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DESIGNING VALVE GEARING.

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BY

EDWARD J. COWLING WELCH,

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PREFACE.

In submitting the following pages to the notice of the engineering profession, I am conscious that I owe some apology for treating of a subject, which has already occupied the attention of so many competent authorities, as Rankine, Zeuner, and others, to whose works I am indebted for much information. For my excuse I must appeal to the fact, with which most engineers are well acquainted, that in "getting out" the details of engine work the question of the valve gearing is frequently the one which presents the greatest difficulty to the designer. To meet this, many of our leading mathematicians have propounded definite formulæ for determining the due proportionment of the various parts; but while these of course ultimately furnish the required results, they necessarily involve such abstruse and complicated mathematical calculations as to be of little or no assistance to the majority of those who most need to use them. To illustrate the truth of this statement, we have but to take the very excellent treatise on valve gears by Dr. Gustav Zeuner. In this work we find enunciated formulæ for almost every description of valve gear, but a glance at its pages will show that these invariably involve an amount of mathematical knowledge which renders their general adoption impossible. It thus comes to pass that in actual practice we frequently find the "rule of thumb" to be the one exclusively resorted to, with a loss of much time and labour in constructing models and adjusting and readjusting their parts until the dimensions of the various details are approximately obtained, and even then it not unfrequently happens that where several engines of the same class have to be constructed, one is first completed in order that the valve gearing may be tested, and the drawings corrected accordingly, before the others are proceeded with. But there are many engines constructed without any such precautions being taken to secure even tolerable accuracy in their valve arrangements, and it is in the case of these that the best results may be looked for from the proper application of the rules which are discussed in this volume. Nor is the question of the correct design of these details one of trifling importance to the users of steam power, for a defective arrangement, such as, upon inquiry, has been too often found to exist, will in many cases involve a loss of from ten to twenty per cent. in fuel and steam. It will thus be seen that this subject is one of general interest, and demands more careful attention than has hitherto been paid to it.

My object in preparing the following problems has been to show that, starting with the application of the 31st Proposition of the 3rd Book of Euclid, to the subject of valve gearing, as first suggested by Professor Zeuner, it is possible to obtain certain geometrical constructions which, without involving a single mathematical calculation, or indeed any other operation that can be performed with a rule and compasses, will yet enable us to obtain results practically as accurate as those deduced from mathematical formulæ, but with this further advantage, that whatever errors may chance to occur in the construction must at once make themselves apparent. I have, moreover, endeavoured to show, step by step, how the results are deducible from the recognised principles of geometry, and at the same time given sufficient explanation of the mode of using the figures as to enable foremen and others to apply them in practice without stopping to investigate the means, by which they have been arrived at. In doing this, I have, as far as possible, avoided the use of mathematical language, substituting for it such ordinary terms as are understood in every drawing office and workshop. It will doubtless be observed I have more than once been compelled to state that many of these results are, after all, only approximately, not absolutely correct; but it will also be easily understood that I have adopted this precaution because in some valve combinations it is almost impossible to obtain either by geometry or mathematical calculation the *exact* movement of all the parts, on which the result depends. In practice, however, *perfect* mathematical accuracy is not required, and the results obtained by the graphic method differ so very slightly from the actual truth as in mechanical construction to be altogether inappreciable.

The problems included in the following pages are applicable to all forms of slide-valve gearing, in which the motion is derived from eccentrics, as now generally adopted; and by a further application of the system, figures for other combinations may be easily obtained.

London, July, 1875.

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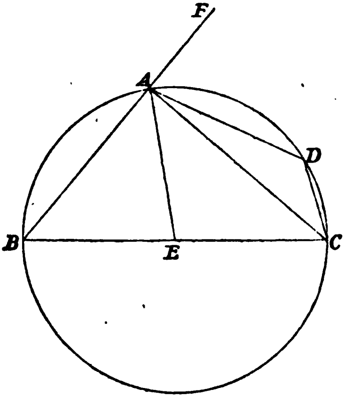
THE theorem, proved in the 31st Proposition of the 3rd Book of Euclid's Elements, and stated in the enunciation to be, that "*in a circle the angle in a semicircle is a right angle; but the angle in a segment greater than a semicircle is less than a right angle; and the angle in a segment less than a semicircle is greater than a right angle,*" is the basis upon which the system, applied in the following pages, is directly founded: and it is therefore so important, before proceeding to its application, to understand clearly the principle itself, as well as the reasoning, by which it has been deduced, as to justify a direct reference to this proposition, the proof of which is given by Euclid in the following words:—

Let *A B C D* be a circle, of which *B C* is a diameter and *E* the centre; and draw *C A*, dividing the circle into the segments *A B C*, *A D C*, and join *B A*, *A D*, *D C*: the angle in the semicircle *B A C* shall be a right angle; but the angle in the segment *A B C*, which is greater than a semicircle, shall be less than a right angle; and the angle in the segment *A D C*, which is less than a semicircle, shall be greater than a right angle.

Join *A E*, and produce *B A* to *F*.

Then, because *E A* is equal to *E B* (Euc. I. Definition 15), the angle *E A B* is equal to the angle *E B A* (Euc. I. 5); and, because *E A* is equal to *E C*, the angle *E A C* is equal to the angle *E C A*; therefore the whole angle *B A C* is equal to the two angles, *A B C*, *A C B* (Axiom 2).



But *F A C*, the exterior angle of the triangle *A B C*, is equal to the two angles *A B C*, *A C B* (Euc. I. 32); therefore the angle *B A C* is equal to the angle *F A C* (Axiom 1), and therefore each of them is a right angle (Euc. I. Definition 10).

Therefore the angle in a semicircle *B A C* is a right angle.

And because the two angles *A B C*, *B A C*, of the triangle *A B C*, are together less than two right angles (Euc. I. 17), and that *B A C* has been shown to be a right angle, therefore the angle *A B C* is less than a right angle.

Therefore the angle in a segment *A B C*, greater than a semicircle, is less than a right angle.

And because *A B C D* is a quadrilateral figure in a circle, any two of its opposite angles are together equal to two right angles (Euc. III. 22); therefore the angles *A B C*, *A D C* are together equal to two right angles.

But the angle *A B C* has been shown to be less than a right angle; therefore the angle *A D C* is greater than a right angle.

Therefore the angle in a segment *A D C*, less than a semicircle, is greater than a right angle.

Wherefore, *the angle*, &c. Q. E. D.

For our present purpose, however, the principle may be enunciated as follows:—

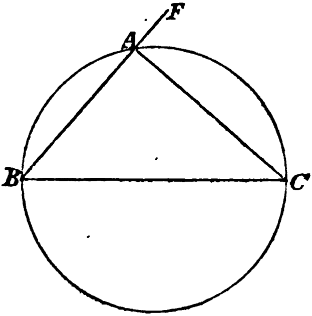


Fig. 1.

If from either end *B* or *C*, (Fig. 1), of the diameter *B C* of the circle *A B C*, a straight line *B F* be drawn cutting the circumference in any point *A*, and from the other end, *C*, of the diameter a straight line, *C A*, be drawn perpendicular to the line *B F*, then this perpendicular *C A* will cut the line *B F* in the same point, *A*, in which this line *B F* cuts, or is cut by, the circumference of the circle *A B C*: and therefore, without drawing the perpendicular *C A*, we know that it would, if drawn, cut the line *B F* in that point, *A*, in which this same line *B F* cuts, or is cut by, the circle *A B C*; and it is the part *B A* of this line, *B F*, which falls within the circumference of the circle *A B C* (and termed the ***radius vector***), which we shall have occasion to make use of, hereafter, as representing the centre line of the crank, the point *A* coinciding with the centre of the crank-shaft.

We will next proceed to explain the backward and forward motion of the slide-valve, as the eccentric sheave revolves with the crank-shaft.

Let the line *C D* (Fig. 2) represent the full travel of the valve, and the point *A* the middle point of that line, and hence, relatively, the central position of the valve, so that the valve slides an equal distance on each side of the point *A*: then *A C* and *A D* are each equal to half the travel of the valve. Upon *C D* as a diameter describe a circle, *C B D*, of which the point *A* will of course be the centre. Now as the throw of an eccentric sheave is equal to half the travel of the valve it drives, *A C* or *A D* represents the throw of the eccentric sheave which will cause the valve to travel a distance equal to *C D*, and the points *C* and *D* will represent, alternately, the centre of the sheave, as the valve arrives at one extreme end of its stroke or the other. Draw *A B* perpendicular to *C D*. Then the point *B* will represent the centre of the eccentric sheave when the valve is in the middle of its travel, for the theoretical deviation from this point, caused by the angular motion of the eccentric rod, is really so small as to be, in practice, imperceptible, and may therefore be disregarded throughout. If we suppose that the crank-shaft turns round, moving the centre of the sheave from *B* to *F*; then, since the line *A B* is a perpendicular drawn through the middle position of the valve, the distance the centre of the eccentric sheave moves from this line is the same as the distance the valve moves from its middle position, and therefore the line *M F* drawn from *F* perpendicular to *A B* represents the distance the valve has moved from its central position *A* towards *D*, whilst the centre of

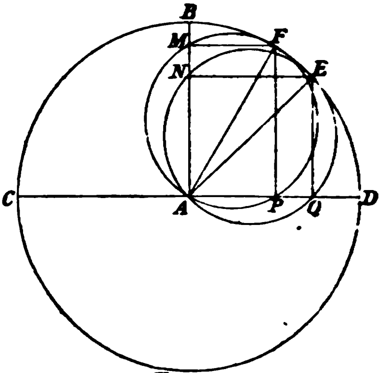


Fig. 2.

the eccentric sheave has moved from *B* to *F*. From this point *F* drop a perpendicular *F P* on to *C D*, cutting *C D* in the point *P*. Then since *B A* is also perpendicular to *C D*, *F P* is parallel to *B A*, and *A P* is equal to *M F*; therefore *A P* also represents the distance the valve has travelled from its central position *A* towards *D*, whilst the centre of the eccentric sheave has moved from *B* to *F*; and if we consider the line *A F*, which represents the throw of the eccentric sheave, to represent also the diameter of a circle, through one end *A* of which the line *A D* is drawn; then the circumference of this circle will, as we have already shown, cut the line *A D* in the same point, in which it would be cut by a perpendicular dropped upon it from the point *F*, which is the other end of the diameter *A F*, and at the same time the centre of the eccentric sheave. Upon this line *A F*, as a diameter, describe the circle *A M F P* which will cut the line *A D* in the point *P*, where the perpendicular dropped from the point *F* upon the line *A D* also cuts it, and the line *A P*, representing the distance the valve has travelled from its central position *A* towards *D*, whilst the centre of the sheave has been moved from *B* to *F*, is also that portion of the line *A D*, which falls within the circumference of the circle, and is therefore the *radius vector*, as we have already explained. Hence it will be seen, that a circle having for its diameter a line, which represents the throw and angular position of the eccentric sheave, demonstrates, by means of the *radius vector*, drawn parallel to the virtual direction of motion of the valve, the exact distance that the valve has travelled from its central position for that particular angular advance of the eccentric sheave; and if the centre of the sheave is caused to advance beyond the point *F*, say for instance to the point *E* (the valve circle, *A M F P*, being supposed to advance with it), it will be seen that the *radius vector* increases in length exactly as the distance between *F*, the centre of the eccentric sheave, and the line *B A* increases; until, when the centre of the sheave reaches the point *E*, the *radius vector* shows that the valve has travelled from its central position *A* towards *D*, a distance, *A Q*, equal to *N E*.

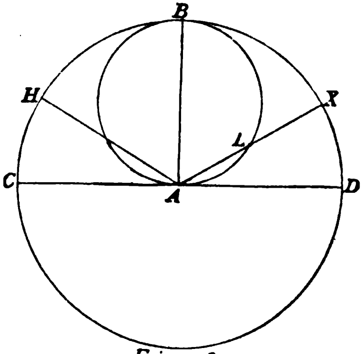


Fig 3

Now, as it would be most inconvenient to cause the centre line, *A B* (Fig. 3), of the sheave, with the valve circle *A B L* upon it, to advance about the centre *A*, towards *D*, we cause, instead, the line *A D* to advance about the same centre and through the same angular distance, as the centre line, *A B*, of the sheave is supposed to advance, but in the opposite direction, that is, towards *B*; for instance, if instead of causing the centre line, *A B*, of the sheave to advance about the point *A* to the position as shown at *A F* (Fig. 2), taking with it the valve circle, *A M F P*, of which it is the diameter, we cause the line, *A D* (Fig. 3), to advance about the same point *A*, and through an angular distance equal to *B F* (Fig. 2), but towards *A B* (Fig. 3), for example to *A X*, that is in a direction opposite to that, in which the centre line, *A B*, of the eccentric sheave is supposed to be advancing, we obtain the same result; for, whether the centre line of the sheave advances, with the valve-circle upon it, towards *A D*, or whether the line *A D* advances in the opposite direction towards the centre line, *A B*, of the sheave, while the sheave itself remains still, it matters not, as in either case, provided the angles of advance are equal, the circumference, *A L B*, of the valve-circle will be intersected in the same point *L*, in the first case by the line *A D* (Fig. 2), and in the second by the line *A X* (Fig. 3), and the line *A L* will be the *radius vector* and represent the distance the valve has travelled from its central position *A* towards *D* for an angular motion of the eccentric sheave equal to *B F* (Fig. 2).

The relation which exists between the motion of the crank and the motion of the slide-valve must now be considered. In the first place, the sheave is of course firmly keyed to the crank-shaft and consequently revolves with the crank; so that, supposing the centre of the crank to be in the direction *A C* (Fig. 2) when the centre of the sheave is in the direction *A B*, then in order to advance the sheave through the angular distance *B F*, the crank must be advanced through an angular distance equal to *B F;* and we have already shown that to ascertain the amount the valve travels from its central position, for any angular advance of the sheave, it is only necessary to cause the line *A D* to advance towards *A B* (the centre line of the sheave), through the same angular distance, as the sheave is supposed to advance, but in an opposite direction. And here we must explain that when we speak of a line advancing towards another line, we merely use the expression to indicate the *direction,* in which any such line is supposed to advance, and not in any way to limit its advance, thus when we say *A D* is to advance towards *A B*, we do not mean to imply that *A D* may not pass *A B*, if necessary, but that *A D* shall advance in that direction in which *A B* is with reference to *A D* before *A D* commences to advance.

We have already shown that the crank must advance through the same angular distance as the sheave; therefore, in order to ascertain the distance the valve has travelled from its central position for any angular advance of the crank, we have only to make use of the same system as we adopted for the advance of the sheave, and cause the line *A D* to advance through an angular distance towards *A B*, equal to that through which the crank, *A C*, is supposed to advance in the opposite direction; for instance, the crank, *A C* (Fig. 3), is supposed to advance through the angular distance *C H*, and we require to know the distance the valve is from its centre of motion for the position, *H A*, of the crank, and to simplify the matter we assume, for the present, that the valve is at its central position, when the crank is at either of its dead points *A C* or *A D*. We now cause the line *A D* to advance towards *A B*, through an angular distance *D X*, equal to *C H*, when the *radius vector*, *A L*, on the line *A X* gives us at once the distance the valve has travelled from its centre of motion towards *D* for the position *H A* of the crank; we have only, therefore, to place the line *A X* at the same angle relative to its horizontal position *A D*, as the given position of the crank occupies relative to its position, *A C*, at the dead point *C*, in order to at once ascertain, by means of the *radius vector* on the line *A X*, the distance the valve is from its centre of motion, for that position of the crank whatever it may be, and whether the sheave is so placed that, when the crank is at either of its dead points, the valve is in its central position (Fig. 3), or some distance, such as *A P* (Fig. 2), from the same.

We will next proceed to point out the application of the system to a simple valve gear. Draw the line *C D* (Fig. 4), representing the direction of the travel of the end of the eccentric rod furthest from the sheave, and it is in this line that the point *A*, the centre of the crank-shaft, will lie. Draw *B G* at right angles to, and intersecting, *C D* in any point *A*, and let *C A* represent

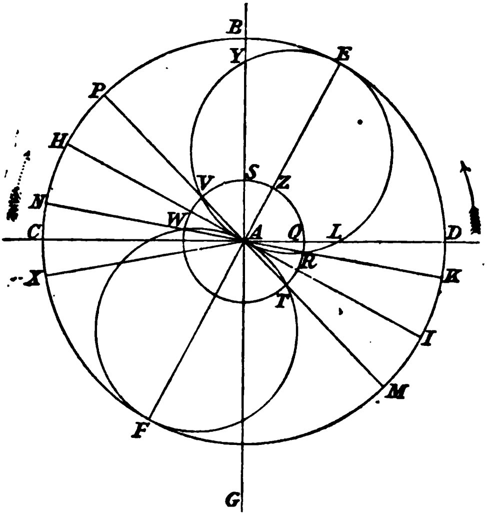


Fig. 4.

the centre-line of the crank when at the dead point *C*. Draw *A E* equal to the throw of the eccentric sheave, and with the same angular advance with regard to *C A* as the eccentric sheave really has with regard to the centre line of the crank. Upon *A E* as a diameter describe a circle, which will be what is termed the *primary* valve circle, because *A E* represents the actual throw of the eccentric sheave, and its position with regard to the crank. The *secondary* valve circle is that described touching the primary valve circle at the point *A*, and having its diameter equal to, and in continuation of, the diameter *A E*. Next, from the centre *A*, and with the radius *AE*, describe the circle *E D F C*, and from the same centre, with a radius equal to the outside lap of the valve, describe the circle *V Q T*, which is termed the *lap-circle.* Now in the position, in which we have assumed the eccentric sheave to be, relative to the crank, this latter would really revolve in the direction of the dotted arrow; but, for the purposes of our diagram we may, as we have already explained, assume that the line *A D* is the centre line of the crank, and cause it to revolve about the point *A*, through the same angular distance as the real centre line of the crank is supposed, in each case, to advance, but in the direction of the dark arrow, that is, in a direction opposite to that in which the crank is really advancing. At the commencement of the stroke the crank will thus be in the position *C A;* but assuming it to be in the direction *A D*, *E V L* being the valve-circle, the *radius vector*, *A L*, on the line, *A D* shows us at once the distance the valve is to the right of its central position *A*, that is, towards *D*. Now, as *A Q* (Fig. 5) represents the lap of the valve, and the line *A Q* (Fig. 4) is a radius of the lap-circle *V Q T*, whose radius was originally made equal to the lap of the valve, therefore the line *A Q* (Fig. 4) also represents the lap of the valve, and as the valve has moved a distance *A L* to the right of its central position, when the crank is really

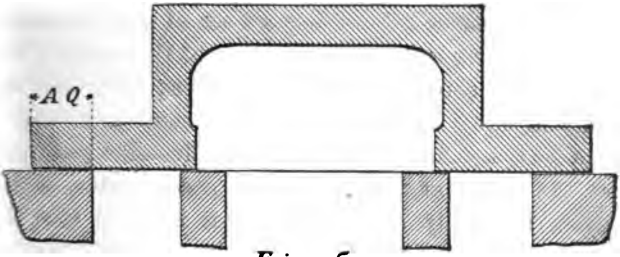


Fig. 5.

at its dead point *C A*, and does not commence to open the port until it has moved a distance equal to the lap *A Q*, therefore in moving from its central position *A* to *L*, it moves a distance *A Q*, before beginning to open the port, which it commences to do when it reaches the point *Q*, opening it a distance equal to *Q L*, so that when the crank is at the beginning of its stroke, viz. in the position *C A*, the port is already open an amount equal to *Q L*, and the amount that the valve is open, when the crank is on its dead point, is termed its *lead*. In the same manner it may be ascertained how much the port at the other end of the cylinder is opened into the exhaust, while the crank is in this position *A C*; to do this it is only necessary with the point *A* as centre and with a radius equal to the *inside* lap of the valve to describe a circle in the place of the *outside* lap-circle, *V Q T*. We have already shown that when the crank is at the commencement of its stroke the valve is open an amount equal to *Q L*, and we have assumed, for the purposes of our diagram, that *A D* represents this position of the crank; we have also shown that the valve has to move an amount equal to *A Q* before it commences to open the port, and in order, therefore, to find that position of the crank, at which the port just commences to open, it is only necessary to bear in mind that it must be such a position as will give a *radius vector* on the assumed centre line of the crank equal to *A Q*. Now the lap-circle, *V Q T*, and the valve-circle, *E V L*, intersect in the point *R*, and the radius *A R* is of course equal to the radius *A Q*, and hence to the lap of the valve, and *A R* is the *radius vector* on the line *A K*, which *radius vector* also represents the amount the valve has moved when the port just commences to open, hence it follows that *A K* is the assumed position of the crank when the valve commences to open the port, its real position being *A X*, for, as we have already explained, the assumed position of the crank is at the same angular distance from *A D*, as the real position is from *C A*, ut set off as revolving in an opposite direction: ut to simplify matters, let it be understood for the ture, that when we speak of the position of the crank we mean, in *all* cases, its *assumed* position, unless in any particular case we distinctly state that it is its *real* position to which we are alluding. Continuing therefore our investigation of the valve diagram (Fig. 4) we have already shown that the valve commences to open the port when the crank is in the position AK, we can in like manner show that the valve just closes the port when the centre line of the crank reaches the position AP, and passes through the point in which the valve and lap circles again intersect, for the *radius vector*, VA, is then exactly equal to the lap of the valve, and represents, of course, the amount the valve has to travel before it reaches its central position, in the same way as when the crank was in the position AK, the valve had travelled from its central position an amount, AR, also equal to its lap, and was just about to begin to open the port; if we now take an intermediate position of the crank, equidistant from AK and AP, we shall find that at this position of the crank the port will be open its greatest amount EZ, and that such position of the crank will exactly coincide with AE, the diameter of the primary valve-circle. We have hitherto treated of the valve as only moving to the right of its central position, we will therefore now proceed to examine its movements to the left of that position, and in order to do this we have only to continue the line *E A* till it again meets the circumference of the circle, *E D F C*, in the point *F*, then *A F* will be equal to *E A*, and upon *A F* as a diameter we describe the circle *F T W*, which will be what is termed the *secondary* valve-circle, and it will touch the primary valve-circle, *E V L*, at the point *A*. Now when the assumed centre line of the crank cuts the primary valve-circle it demonstrates that the valve itself is either on the right or left of its central position according as the original position of the assumed centre line of the crank, before the stroke commences, is at the dead point on the right or left of the centre line *B G*; for instance, if the real position of the crank, with reference to the real position of the sheave were at the dead point *A C* (Fig. 4), then the original position of the assumed centre line of the crank would be at the dead point on the right of *B G*, viz., at *A D*, and *vice versâ*, but now, supposing it to be at *A D*, should the (assumed) centre line of the crank intersect the primary valve-circle *E V L*, it would demonstrate that the valve was to the right of its central position, and if it intersected the secondary valve-circle it would show that the valve was to the left of such position, its distance from its central position in either case being shown by the length of the *radius vector* on the centre line of the crank, in whatever position it may be at that moment. From the foregoing, it is quite clear that the valve must be at its central position, when the centre line of the crank is midway between the two valve-circles *E V L* and *F T W*, that is in the direction *A H* or *A I*, at right angles to the line, *E F*, containing the diameters of the two valve-circles; so that, in order to find the position of the crank at which the valve is in its central position it is only necessary to draw a line, *H I*, at right angles to the line *E F*, and intersecting it in the point *A*. And in order to ascertain the amount the port is open for any given position of the crank, we have only to consider that the valve has to travel an amount equal to the radius of the lap-circle before it commences to open the port, hence we have to deduct this amount from the length of the *radius vector* for any such position of the crank, and the length that remains of the *radius vector* represents the amount that the port is open, and is that portion of the *radius vector* lying between the circumference of the lap-circle and the circumference of the valve-circle, thus when the crank is in the position *A B* (Fig. 4), *A Y* is the *radius vector* and represents the amount that the valve is to the right of its central position, but it had to travel an amount equal to *A S* before it began to open the port, and therefore *S Y*, the length that remains of the *radius vector* after deducting an amount, *A S*, equal to the radius of the lap-circle *V Q T*, represents the amount that the port is actually open for the position, *A B*, of the crank. Having now investigated the general principles, upon which this valve system is based, we will proceed to show how the proportions of the various parts of a valve gear, and the relative movements of the same can be at once determined.

SIMPLE VALVE GEAR.

PROBLEM I.

The throw of the eccentric sheave, the external lap of the valve, and the amount of lead required, being known; to find the position of the crank when the steam is cut off, and the position of the sheave relative to the centre line of the crank.

Draw the lines *C D*, *B G* (Fig. 6) perpendicular to each other, and intersecting in the point *A*. With this point as a centre, and with a radius *A Q*, equal to the lap of the valve, describe the lap-circle *V Q T*; and from the same centre, with a radius equal to the throw of the eccentric sheave, describe the circle *B D M C*. From the point *Q* on the line *A D*, set off *Q L* equal to the required lead; and at the point *L* erect the perpendicular *L O*, cutting the circle *B D M C* in the point *E*. Join *E A* and produce it till it again cuts the circle *B D M C* in a point *F*. Upon *E A* and *A F* as diameters describe the valve-circles *E L V* and *F W T*, these will be the *primary* and *secondary* valve-circles respectively, and *A E*, the diameter of the primary valve-circle, will represent the centre line of the sheave, when the *real* position of the crank is represented by the line *C A*, the

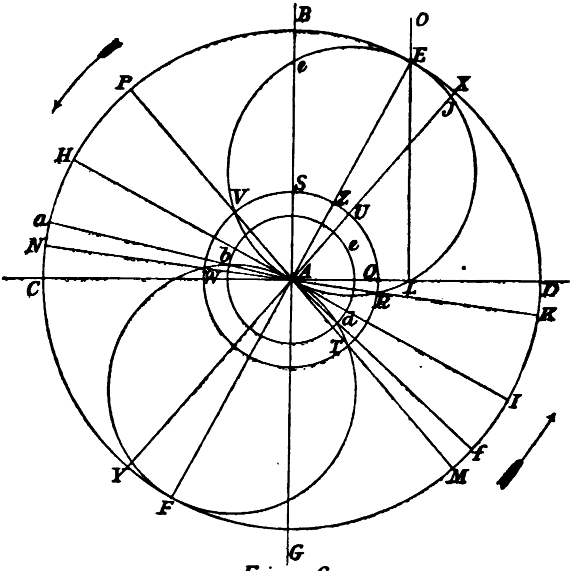


Fig. 6

angle *B A E* is therefore the angle of advance, and the line *A P*, drawn through the point of intersection, *V*, of the lap and valve circles, represents the (assumed) position of the crank at the moment the steam is cut off, the *real* position of the crank being, at that moment, at the same angular distance from *C* that the assumed position is from *D*; but is set off, as we have previously explained, as revolving in the opposite direction. The line *A F*, which is the diameter of the secondary valve-circle, would represent the centre line of the sheave, if the *real* position of the crank were represented by the line *A D*, in both cases of course the crank and eccentric sheave would be revolving in the opposite direction to the arrows in the diagram. Returning, however, to the method of applying the diagram, *A D* is the (assumed) position of the crank, when *A E* represents the centre line of the eccentric sheave, this crank revolving in the direction indicated by the arrows, it being at the same time assumed that the sheave itself does not revolve, but remains with its centre line in the direction *A E*, the line *H I* represents the position of the crank, either in the direction *A H* or *A I*, when the valve occupies its central position. We will now suppose our crank to be in the position *A I*, and as it revolves in the direction indicated by the arrows as soon as it begins to move from the position *A I* it will be intersected by the primary valve-circle, that portion of the centre line of the crank, measured from the point *A* to the point of such intersection, being the radius vector of the primary valve-circle, shews the amount the valve has moved to the right of its central position, because the original position of the assumed centre line of the crank is on the right of *B G*, and deducting from this radius vector that portion which falls within, and forms a radius of the lap-circle *V Q T*, the remainder, if any, gives us, as we have already shewn, the amount that the valve has actually opened the port, for any particular position of the crank. We will next suppose that the crank has reached the position *A K*, *A R* is now the radius vector, demonstrating that the valve has moved an amount equal to *A R*, to the right of its central position, but *A R* is also a radius of the lap-circle, and is equal to the other radius, *A Q*, of the same circle, and *A Q* was made equal to the lap of the valve, therefore *A R* is also equal to the lap of the valve. Now, it is evident that the valve must have travelled an amount equal to *A Q* or *A R* equal to *A B* (Fig. 7), when it commences to open the port, and as we have already shewn that when the crank is in the position *A K* (Fig. 6) the valve has then travelled this amount, it is clear that *A K* represents that position of the crank at which the valve just commences to open the port and admit steam into the cylinder. We will next suppose the crank to have reached the position *A D*, *A L* will now be the radius vector, deducting from this the radius *A Q* of the lap-circle, or what is the same thing, only taking into consideration that portion of the radius vector, which lies between the circumference of the lap-circle, and the circumference of the valve-circle, we have *Q L* representing the amount that the valve has actually opened the port for the position *A D* of the crank, and as in this position the crank is at one of its dead points, the amount that the port is now open, is termed the *lead* of the valve, and in constructing our diagram (Fig. 6) we made *Q L* equal to the lead that was given. Following the crank as it revolves, we find that when it has reached the position *A X* the port is open an amount equal to *U J*, and when in the position *A E* the port is open an amount equal to *Z E*, which is its greatest opening, for as the crank moves beyond this position, the radius vector becomes less, and the valve commences to close the port again, thus when the crank has reached the position *A B*, the port is only open an amount equal to *S e*, and in the position *A P* the radius vector, *A V*, of the valve-circle is again only equal to the radius of the lap-circle, in this position, therefore, of the crank, the valve has just closed the port, hence *A P* is that position of the crank, at which the admission of steam to the cylinder ceases and expansion begins, and when the crank has reached *A H*, the valve is again in its central position, and as the crank passes from *H* to *I*, intersecting the secondary valve-circle, the valve opens and closes the port at the right-hand end of the cylinder, in the same way and in the same relative positions of the crank, as it did at the left-hand end, whilst the crank was intersecting the primary valve-circle. In precisely the same manner, by making the lap-circle

V Q T with a radius equal to the inside lap of the valve, the opening and closing of the port, on the exhaust side of the valve, can be ascertained, only it must be borne in mind, that when the valve moves to the right of its central position, the port at the right-hand end of the cylinder is opening into the exhaust, while at the same time the port at the left-hand end of the cylinder is opening into the steam chest to admit steam into that end of the cylinder, and *vice versâ.* Now, supposing that it is required that the exhaust shall open when the crank reaches the position represented by the line *A a* (Fig. 6), let this line intersect the secondary valve-circle in the point *b*, then from the centre *A*, and with radius *A b*, describe the circle *b e d;* this will be the inside lap-circle, and its radius will represent the inside lap of the valve. If we examine this part of our diagram further, we shall find that the exhaust again closes at the position *A f* of the crank, at this point therefore compression begins.

Application of the Diagram.

We will next proceed to show how the diagram is applied to designing the slide-valve and port-faces. In the horizontal line, *X Y* (Fig. 7), take any point *X*, and set off *X A* equal to *A E* (Fig. 6), representing the travel of the valve from its central position towards *X*, the point *A* (Fig. 7) will now represent the end of the valve. This diagram (Fig. 7) is drawn, however, to a smaller scale than the previous one (Fig. 6). From *A* set off *A B* equal to *A Q*

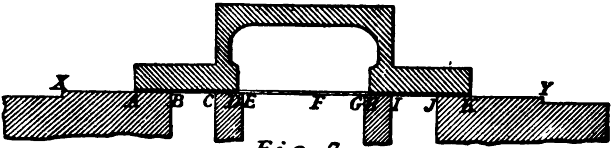


Fig. 7.

(Fig. 6), this will represent the outside lap. From *B* (Fig. 7) set off *B C* equal to *Z E* (Fig. 6), this will be the length of one steam-port measured in the direction of the motion of the valve. From *C* (Fig. 7) set off *C D* equal to *A b* (Fig. 6), this will represent the inside lap of the valve. From *C* (Fig. 7) also set off *C E*, the length of the bar dividing the steam from the exhaust-port; this may be of any convenient length, provided it is of sufficient strength to resist the pressure of the steam, and give a fair bearing surface. In the present case we will make it equal to half *B C*, that is, equal to half the length of the port. From *D* set off *D F* equal to *A E* (Fig. 6), the travel of the valve, and from *F* (Fig. 7) set off *F G* equal to *B C*, the length of the steam-port, *E G* will now represent the length of the exhaust-port: and to complete our valve and port-faces, we have only to make the bar *G I* equal to *C E*, and set back the inside lap *I H* equal to *C D*, and from the point *I* to set off the second steam-port *I J*, equal to the steam-port *B C*, and the external lap *J K* equal to the external lap *A B*, and the sliding-face *K Y* equal to the sliding-face *X A*, our valve and port-faces are then completed.

PROBLEM II.

The throw of the eccentric sheave, the position of the crank, when the steam is cut off, and the amount of lead required, being known; to find the proper lap of the valve, and the position of the sheave relative to the centre line of the crank.

This problem is one that is frequently met with in practice, and the following will be found to be a very simple method of solving it. Draw the lines *B G* and *C D* (Fig. 8) perpendicular to each other, and intersecting at the point *A*; with this point as a centre, and with a radius equal to the given throw of the eccentric sheave, describe the circle *B D G C*. Draw *A P* to represent the given position of the crank when the steam is to be cut off, this representative position, *A P*, of the crank in the diagram (see p. 10) being drawn at the same angular distance from *A D* as the given position of the crank itself, when the valve closes the port, is from its *real* position at the commencement of that stroke of the piston. We next take as a centre the point *D*, at which the line *A D* intersects the circle *B D G C*, and with a radius equal to the given lead of the valve, we describe the circle *H T*, which we shall henceforth term the *lead-circle*, th from the point *P* draw a straight line touching th lead-circle at the point *H*, and cutting the circ *B D G C* in the point *K*. Join *A K*, and from th centre *A* describe a circle, *V Z R*, touching the lin

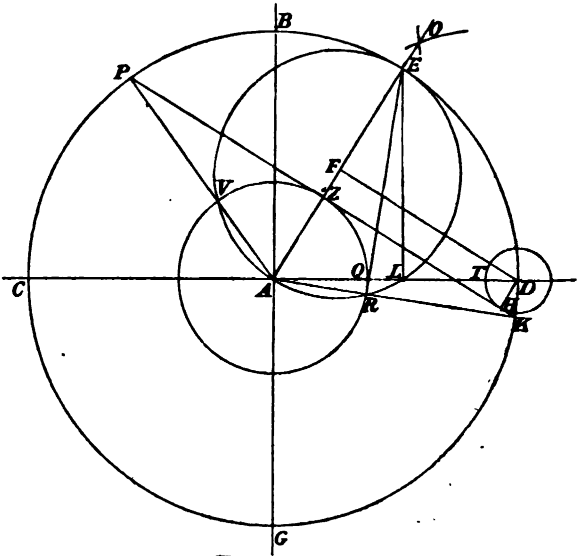


Fig. 8.

P K at the point *Z*, this circle, *V Z R*, will be the lap-circle. From *P* and *K*, as centres, describe arcs intersecting at the point *O*. Join *A O*, cutting the circle, *B D G C*, in the point *E*, then *A O* will be at right angles to *P K*, and *A E* will be the real position of centre line of the eccentric sheave when AC resents the real position of the crank, upon AE a diameter describe the valve-circle ELV, which l cut the lap-circle in the points R and V, in which ints it is already intersected by the lines AP and K. Then AK is the position of the crank when e valve just commences to open the port, and QL equal to DT, the radius of the lead-circle, which as originally made equal to the given lead, there-re the amount of lead, QL, is equal to the given mount of lead. It is also clear that the valve has ust closed the port in the given position, AP, of the rank, at which it was required that the steam hould be cut off, and the radius of the lap-circle, VZR, represents the amount of lap that the valve ought to have, in order that the various given requirements may be fulfilled.

As it may not be quite evident to everyone, at first sight, why it is that QL, representing the amount of lead of the valve, should be exactly equal to the radius of the circle, TH, which we have termed the *lead-circle*, and the use of which is now introduced for the first time, we will proceed to show how this equality between QL and the radius of this circle exists. Join ER and EL (Fig. 8), which will be perpendicular to AK and AD respectively (Euclid III. 31). Draw DF parallel to KZ. Join DH, which will of course be equal to FZ. Then in the triangles EAR, KAZ, we have *E A* equal to *A K*, and the angle *E A K* common to the two triangles, and the angle *E R A* equal to the angle *K Z A*, both being right angles, therefore the triangles *E A R* and *K A Z* are in every respect equal to each other, and the side *A Z* is equal to the side *A R*. Again, in the triangles *E A L*, *D A F*, we have *E A* equal to *A D*, and the angle *E A D* common to the two triangles, and the angle *E L A* equal to the angle *D F A*, both being right angles, therefore the triangles *E A L* and *D A F* are in every respect equal to each other, and the side *F A* is equal to the side *A L*; but *Z A* has been proved to be equal to *A R*, and *A Q* is equal to *A R*, being a radius of the same circle *V Z R*, therefore *A Z* is also equal to *A Q*, and these form parts of the equal lines *A F* and *A L*, therefore the remaining parts *Z F* and *Q L* of these lines are equal to each other, but *Q L* represents the amount of lead of the valve, therefore *F Z* also represents this lead, and *F Z* has been shown to be equal to *D H*, therefore *Q L* is also equal to *D H*, which is a radius of the lead-circle, and made equal to the given amount of lead, therefore the lead *Q L* is equal to the given amount of lead.

PROBLEM III.

The amount that the port is to be open for any particular position of the crank, the position of the crank itself when the steam is cut off, and the amount of lead being known; to find the lap of the valve, the throw of the eccentric sheave, and its position with regard to the centre line of the crank.

This problem, and the next, which is a modification of it, are certainly by far the most important problems in conjunction with simple valve gearing, and they are at the same time about the most difficult to solve by calculation. The author has arranged the following very easy graphical method of solving them, by means of which results are obtained, which are absolutely correct, excepting only as far as the theoretical deviation, due to the angular motion of the eccentric rod, is concerned, and which deviation, as we have already mentioned, is perfectly inappreciable in practice.

Draw AB (Fig. 9) to represent the amount the port is to be open at the given position of the crank, and make AC to represent the required amount of lead. From the point C draw CD to represent the position of the crank at which the steam is to be cut off from the cylinder. Draw *C E* at right angles to *C D* and *A F* at right angles to *A B*, intersecting the line *C E* in the point *G*; set off *G E* equal to *G F*,

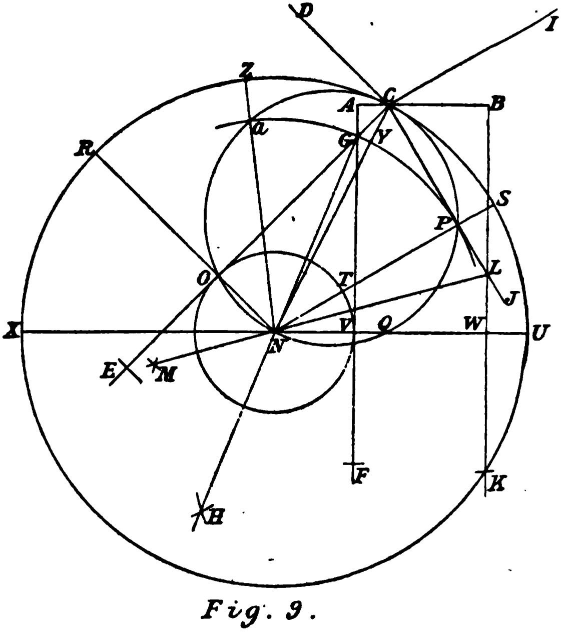


Fig. 9.

and with the points *E* and *F* as centres and with equal radii describe arcs intersecting at the point *H*. Join *H G*. From the point *C* draw *C I* to represent the position of the crank at which it is required that e port shall be open the given amount *A B*. Draw *J* at right angles to *C I*, and from the point *B* draw *K* perpendicular to *A B*, intersecting the line *C J* n the point *L*. Set off *L K* equal to *L C*, and with he points *K* and *C* as centres and with equal radii lescribe arcs intersecting at the point *M*. Through he points *M* and *L* draw a straight line intersectng the line *G H* in the point *N*; then this point *N* will represent the centre of revolution of the eccentric sheave, that is the centre of the crank-shaft, and the point *C* will represent the centre of the sheave itself. Join *N C*, which will be the diameter of the primary valve-circle, and represent the throw of the eccentric sheave and its position relative to the *real* position *X N* of the crank. Upon this diameter describe the primary valve-circle *C Q N*, and from the centre *N* describe the circle *O T V*, touching the lines *G E* and *G F*, this will be the lap-circle, and will represent by its radius the required lap of the valve. Again from the centre *N*, and with radius *N C*, describe the circle *C K X*, and from the point *N* draw *N R*, passing through the point of intersection *O* of the lap and valve circles, and *N S*, passing through the point *P*, where the valve-circle cuts the line *C J*. Then draw *N U* parallel to *A B*. It will now be quite clear that, in the position *N S* of the crank, the port will be open an amount *T P*, and this position represents the given position *C I*, because *N S* is parallel to *C I*, both being at right angles to *C J*, and the amount of opening, *T P*, can easily be shewn to be equal to *V W*, which is again equal to *A B*, the given amount. It will also be seen that the port is just closed and the steam cut off from the cylinder when the crank reaches the position *N R*, which represents the given position *C D*, because *N R* is parallel to *C D*, both being at right angles to *C E*. Again the port is opened an amount *V Q*, when the piston commences its stroke and the crank is at the dead-point *N U*; this amount is therefore the lead, and it is equal to *A C* the given amount of lead, for if we join *C Q*, this line *C Q* will be perpendicular to *N Q* (Euclid III. 31), but *A V* is perpendicular to *N Q*, therefore *C Q* will be parallel to *A V*, and *V Q* being drawn parallel to *A C*, must also be equal to it.

To find the point *N*, it is only necessary to bear in mind that it is that point in the line *G H*, which is equidistant from the line *C J* and the perpendicular *B K*, and in practice it may easily be found by trial with a pair of compasses.

In cases in which *T P* represents the whole length of the port in the steam chest (measured of course in the direction of motion of the valve), from the centre *N* and with radius *N P* describe an arc cutting the valve-circle in the points *P* and *a* respectively and the line *N C* in the point *Y* (this arc does not necessarily pass through the point *G*), then, as we see from the diagram, when the crank is in the position *N S*, the valve is at a distance *N P* rom its central position, and the port is open an mount TP, which we have assumed to be its full pening, but when the crank reaches the position C, coinciding with the diameter of the valve-circle PN, then the valve will be at a distance NC from its central position, but as the port is full open when the valve is at a distance, NY, equal to NP from its central position, it is clear that in the position, NC, of the crank the valve has not only opened the port fully, but has passed a distance, YC, beyond its edge, so that it has to return through this distance before it can *commence* to close the port, and we find that when the crank reaches the position NZ, passing through a, the point of intersection of the arc PYa and the valve-circle CPN, then the valve has returned towards its central position this amount YC, and is just about to commence the closing of the port; from the foregoing it is clear that under these circumstances the port remains open its full amount during the whole time that the crank is travelling from the position NS to the position NZ.

PROBLEM IV.

The greatest amount that the port is to be opened, the position of the crank when the steam is to be cut off from the cylinder, and the amount of lead being given; to find the lap of the valve, the throw of the eccentric sheave, and its position relative to the centre line of the crank.

Draw *A B* (Fig. 10) to represent the greatest amount that the port is to be opened, and set off *A C* to represent the amount of lead required. From the point *C* draw *C D* to represent the position of the crank at which the steam is to be cut off from the cylinder. Draw *C E* at right angles to *C D*, and *A F* at right angles to *A B* and intersecting the line *C E* in the point *G*. Through the point *B* draw *H I* parallel to *A F*, set off *G E* equal to *G F*, and with the points *E* and *F* as centres, and with equal radii, describe arcs intersecting at a point *J*. Join *J G*, and produce it till it intersects the line *H I* in a point *K*. Join *K C*. With the point *G* as centre describe an arc touching the line *H I* and intersecting the line *K C* in the point *L*. Join *L G*, and from the point *C* draw *C M* parallel to *L G* and cutting the line *G J* in the point *M*. Then this point *M* will represent he centre of revolution of the eccentric sheave, that s the centre of the crank-shaft, and the point *C* will

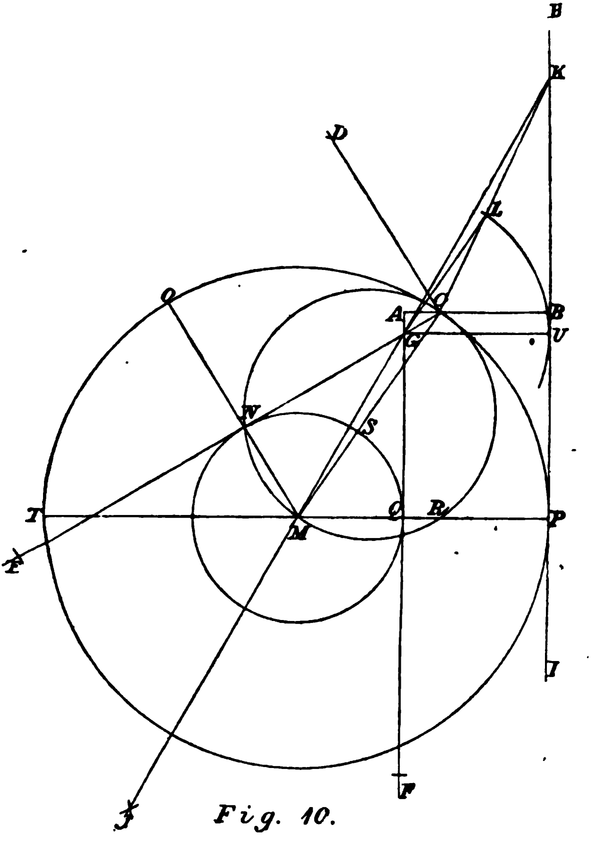


Fig. 10.

represent the centre of the sheave itself, and the line *M C* will be the diameter of the primary valve-circle, and will represent the throw of the eccentric sheave and its position relative to the *real* position, *T M*, of the crank. Upon this diameter describe the primary valve-circle *C R M*, and from the centre, *M*, describe the circle *N S Q*, touching the lines *G E* and *G F*; this will be the lap-circle, and will represent by its radius the required lap of the valve. Again, with the centre *M* and with radius *M C* describe the circle *C P T*, and from the point *M* draw *M O*, passing through the point of intersection *N* of the lap and valve circles, and draw *M P* parallel to *A B*. It will now be quite clear that the greatest opening of the port will be an amount equal to *S C*, and this, as can readily be seen, is equal to *Q P*, which is again equal to *A B*, the given amount. It will also be seen that the port is just closed and the steam cut off from the cylinder when the crank reaches the position *M O*, which represents the given position *C D*, because *M O* is parallel to *C D*, both being at right angles to *C E*. Again the port is opened an amount *Q R* when the piston commences its stroke, and the crank is at the dead-point *M P*, this amount is therefore the lead, and it is equal to *A C* the given amount of lead, for if we join *C R* this line *C R* will be perpendicular to *M R* (Euc. III. 31), but *A Q* is perpendicular to *M R*, therefore *C R* will be parallel to *A Q*, and *Q R* being drawn parallel to *A C* it must also be equal to it.

To find the point M it is only necessary to bear in mind that it is that point in the line GJ which is equidistant from the point C and the line HI, and in practice it may easily be found by trial with a pair of compasses, as soon as we have drawn the line GJ, but as in some cases it may be preferred to find the point M by the construction we have given, and as it may not be quite evident at first sight why the line CM drawn parallel to the radius LG represents the throw and centre line of the sheave, and intersects the line GJ in the point M, so that this point shall be equidistant from the point C and the line HI, we will proceed to explain the connection. Draw GU parallel to MP. Then in the triangle KMC as KM is to KG so is MC to GL, because MC is parallel to GL, and in the triangle KMP as KM is to KG so is MP to GU, because GU is parallel to MP. Hence MC is to GL as MP is to GU, but GL is equal to GU, they being radii of the same circle, therefore as MC is to GL so is MP to GL, and thus MC must be equal to MP.

EXPANSION GEARING.

We have hitherto been investigating the movements of a single slide-valve; we will now proceed to shew the application of the diagram to demonstrate the movements of two slide-valves, either independently or with reference to each other, as usually occurs in expansion gearing.

Let the point *A* (Fig. 11) represent the centre of the crank-shaft, and *A E* the centre line of the ordinary or distribution valve eccentric sheave; at the same time let *A F* represent the centre line of the sheave that moves the second or expansion valve. Join *E F*. Draw *A H* parallel and equal to *E F*, and join *H E*, which will be parallel and equal to *A F*. Upon *A E*, *A F*, and *A H* respectively, as diameters, describe circles; that upon *A E* will be the primary main valve circle, that upon *A F* will be the primary expansion valve circle, and that upon *A H* will be the resultant circle, demonstrating by its radius vector the motion of the expansion valve with reference to the main valve. The line *A E* cuts the three primary circles in the points *E*, *K* and *J* respectively. Then the original position of the (assumed) centre line of the crank being at *A D*, which is the dead-point on the right of the line *B G* (see p. 16), the length of the radius vector *A E* (which in this particular case coincides with and is equal to the diameter) shows that the main or distribution valve is to the right of its central position a distance equal to *A E*; but at this position of the crank the expansion valve is only to the right of its central position a distance equal to *A K*, that is, the

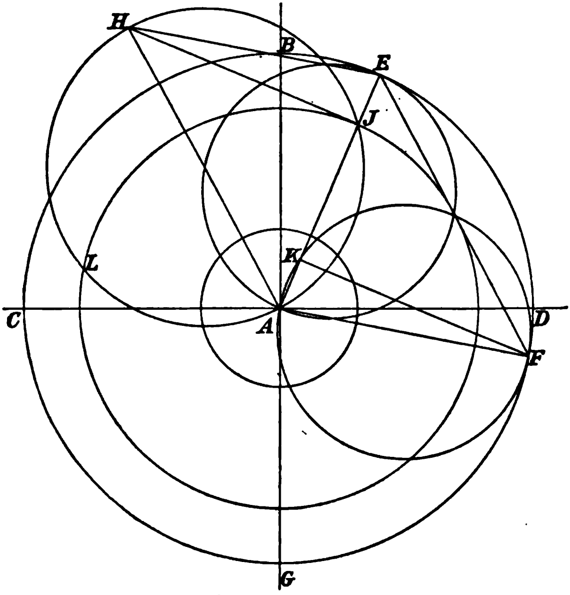


Fig. 11.

difference between the distances of the centre lines of the two valves from their central position, and hence their distance from one another is an amount equal to *K E*; but the radius vector, *A J*, of the resultant circle also represents this distance. Now if from *A*, as a centre, a circle be drawn with a radius equal to the distance that the centres of the valves have to be from each other just when the upper valve closes the port in the distribution valve, then when the crank intersects the points where the resultant circle cuts this circle, the port in the distribution valve will, if the crank is *approaching* the diameter of the resultant circle, just be closing; and if *receding* from the diameter, the port will just be opening.

We will now proceed to show why *A J* is exactly equal to *E K*. Join *H J* and *K F*; then *H A*, having been made parallel and equal to *E F*, the alternate angle *H A E* is equal to the alternate angle *F E A*, and the angles *H J A* and *A K F*, being angles contained in semicircles, are each right angles, and the supplemental angle *F K E* must therefore also be a right angle and equal to the angle *A J H*. Then in the triangles *E K F* and *A J H* the side *H A* is equal to the side *E F*, and the angle *H A J* is equal to the angle *K E F*, and the angle *A J H* is equal to the angle *E K F*; therefore the triangle *E K F* is equal to the triangle *A J H*, and the side *A J* is equal to the side *E K*.

Next we will take the case of the crank being in the position *A R* (Fig. 12). Here the centre lines of the two valves will be distant from their central position and from one another an amount equal to

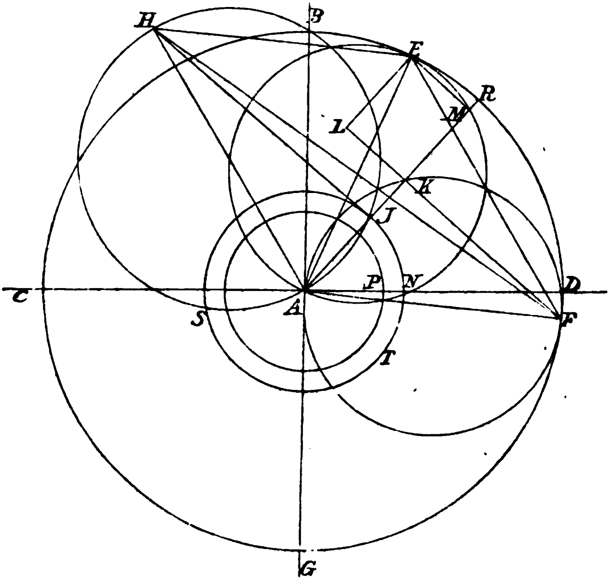


Fig. 12.

K M, but the radius vector, *A J*, of the resultant circle, *H S J*, also represents this distance as before, which we will now proceed to prove. Join *H J*, *E M*, and *F K;* from the point *E* draw a line parallel to *M A*, and meeting *F K* produced in the point *L*.

AH was made equal and parallel to EF, and the alternate angle AEF is equal to the alternate angle EAH, and the alternate angle LEA is equal to the alternate angle JAE; therefore, the whole angle LEF is equal to the whole angle JAH, and the angles AJH and AKF, being angles contained in semicircles, are each right angles and equal to one another. But the angle LKM is equal to the vertical angle AKF, and is therefore also a right angle; and the line EL being drawn parallel to MK the angle ELK is equal to the angle LKM, therefore the angle ELK is also a right angle and equal to the angle AJH. Then in the triangles AJH and ELF, EF is equal to HA, and the angle JAH is equal to the angle LEF, and the angle AJH is equal to the angle ELF, therefore the triangle AJH is equal to the triangle ELF, and the side AJ to the side EL; but EL is drawn parallel to MK, and the angle AKF has been shown to be a right angle, the supplemental angle FKM is therefore also a right angle, and the alternate angle EMK, being the angle contained in a semicircle, is a right angle; therefore the line KL must be parallel to the line EM, and MK equal to EL; but AJ is equal to EL, therefore AJ is also equal to KM.

PROBLEM V.

The respective positions of the crank, at which the exhaust shall be opened and closed, the amount of lead, and the position of the crank at which the steam port in the cylinder shall be closed and the steam cut off by the main valve, being given; to find the position and throw of the eccentric sheave, and the amount of the internal and external laps of the main valve.

In the preceding problems we can cause the exhaust to take place at any position of the crank that we may find necessary by simply making the internal lap of the corresponding amount, but the later in the stroke that we make this exhaust to take place so much the earlier will compression commence, hence if we require the exhaust and the compression each to take place at given positions of the crank, we must construct our diagram accordingly.

In the horizontal line *fg* (Fig. 13) take any point *A*, and draw *A Y* in the direction in which the crank is to be when the exhaust opens, and *A Z* in the direction it is to be when the exhaust closes and compression commences, make *A Y* equal to *A Z*, and from *Y* and *Z*, as centres, describe equal arcs intersecting at any point *b*, through this point draw *A* which will be the line containing the diameters

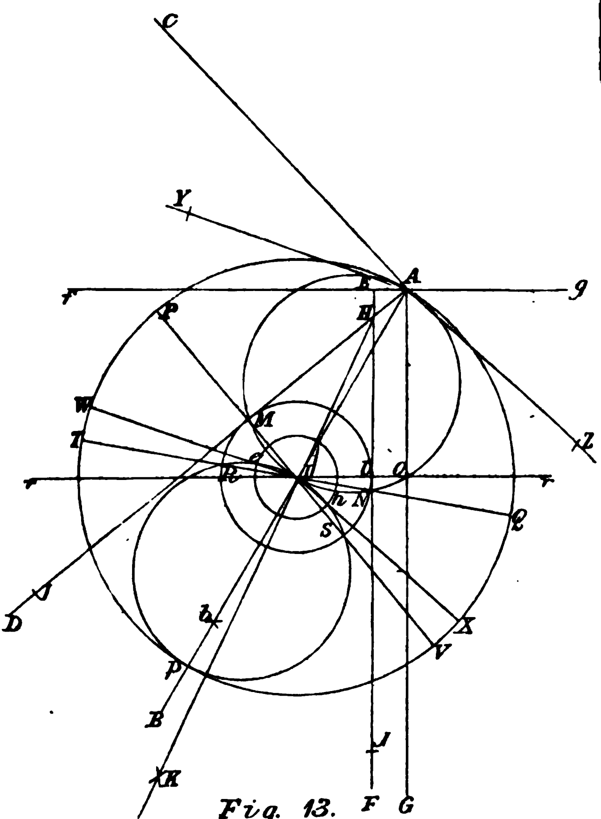


Fig. 13.

the main valve circles. From the point *A* draw *A C* the direction in which the crank is to be when the main valve closes the steam-port in the cylinder, care being taken to arrange that this shall be before the expansion valve re-opens the port in the main valve. From A draw AD at right angles to AC, and upon the line Af set off AE equal to the required lead, and from A and E draw AG and EF each perpendicular to fg, the perpendicular at E intersecting the line AD at the point H: from this point, H, set off HI equal to HJ, and with the points I and J as centres, and with equal radii, describe arcs intersecting at any point K. Join HK cutting the line AB in the point L, which point will represent the centre of the crank-shaft. Through the point L draw rr parallel to fg, then LA will be the diameter of the primary main valve circle, and will represent the position of the main valve eccentric sheave relative to the *real* position, LRr, of the crank. From the centre L, and with radius LA, describe a circle cutting the line AB in the point p. Upon LA and Lp as diameters describe circles, these will be the primary and secondary main valve circles respectively. From the centre, L, describe the circle lMS touching the lines HD and HF at the points l and M respectively; this will be the external lap-circle, and will indicate by its radius the external lap of the main valve. Draw LW and LX parallel to AY and AZ respectively, then LW will represent the position of the crank when the exhaust is to open, and LX its position when the exhaust is to close and compression to commence. Draw *L P* parallel to *A C*, then *L P* will represent the position of the crank at which the main valve closes the port in the cylinder. From the centre, *L*, describe the circle, *e h*, passing through the points, at which either the primary or secondary main valve circle intersects the lines *L W* and *L X*, in the figure before us this intersection taking place with the secondary main valve circle. Then this circle, *e h*, will be the internal lap-circle, and will represent by its radius the internal lap of the valve. Our diagram is now complete, and the results obtained by it are clearly shown to be in accordance with the given particulars.

Although this and the following problem refer more particularly to the action of a single slide-valve, it must be understood that this valve is intended to form the main valve in an expansion combination, in which, as the cutting off of the steam is done by the expansion valve, we are free to place the eccentric sheave of the main valve at such an angle as shall cause the opening and closing of the exhaust to take place at given positions of the crank.

PROBLEM VI.

The respective positions of the crank at which the exhaust is to open and close, the amount of lead, and the amount the steam-port is to be open for a certain position of the crank, being given; to find the position and throw of the main valve eccentric sheave, the point of cut-off of the main valve, and the external and internal laps of the same.

In the horizontal line, MN (Fig. 14), take any point A. From A draw AR in the direction in which the crank is to be when the exhaust opens, and AS in its direction when the exhaust closes, and make AR and AS equal to each other. From the points R and S respectively as centres, and with the same radius, describe arcs intersecting at any point B. Join AB. From A set off AE equal to the required lead, and from the points A and E respectively, draw the lines EH and At perpendicular to MN. From the point A draw AC parallel to the given direction of the crank in which it is required that the steam port shall be open a given amount; from A set off AD equal to this amount, and through the point D draw IG at right angles to AC, and cutting the perpendicular EH in the point G; set off GI and GH equal to each other, and from *H* and *I* as centres and with the same radius describe arcs intersecting at any point *J*. Join *J G* intersecting the line *A B* in the point *K*, which point will represent the centre of the crank-shaft,

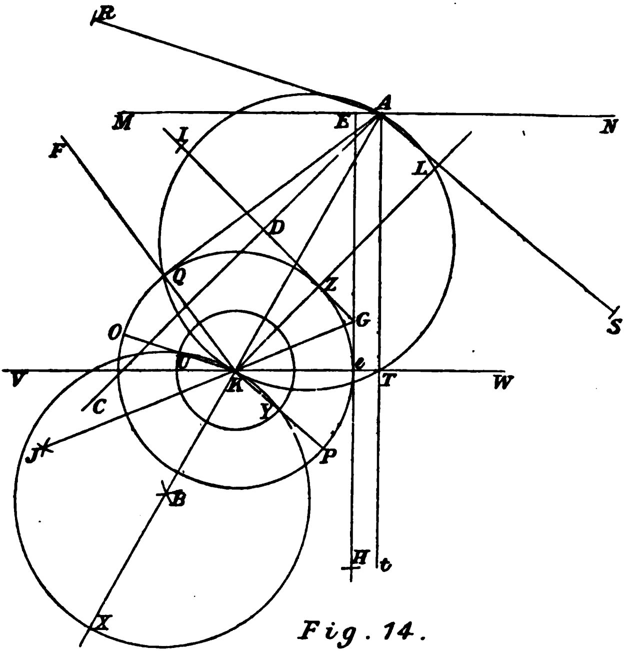


Fig. 14.

and *K A* will represent the throw of the eccentric sheave, and be the diameter of the primary main valve circle. Through the point *K* draw *V W* parallel to *M N;* then the line *K A* represents the position of the eccentric sheave relative to the *real* position *K V* of the crank. Draw *K O* and *K P* parallel to *A R* and *A S* respectively, and with the point *K* as a centre describe a circle touching the perpendicular *E H* at the point *e*, and the line *I G* at the point *Z*, this will be the external lap-circle, and will represent by its radius the external lap of the main valve. Upon *K A* as a diameter describe the primary main valve circle. From *K* draw *K L* parallel to the given direction *A C* of the crank. This line will, of course, pass through the point *Z*. It will now be quite evident from the diagram, that in the given direction *K L* of the crank, the steam-port is open an amount, *Z L*, equal to *A D*, the given amount. From *A* draw *A Q* touching the external lap-circle at the point *Q*, where it intersects with the primary main valve circle. Through the point *Q* draw the line *K F*, which will represent the direction of the crank when the main valve closes the steam-port. Produce *A K* to *X*, making *K X* equal to *K A*, and upon *K X* as a diameter describe the secondary main valve circle intersecting the lines *K O* and *K P* in the points *U* and *Y* respectively. From the centre *K*, and with a radius equal to *K U* or *K Y*, which will represent the internal lap of the valve, describe the internal lap-circle. Our diagram is now complete, and the results obtained by it are in accordance with the given particulars.

Although this and the preceding problem refer more particularly to the action of a single slide-valve, it must be understood that this valve is intended to form the main valve in an expansion combination, in which, as the cutting off of the steam is done by the expansion-valve, we are free to place the eccentric sheave of the main valve at such an angle as shall cause the opening and closing of the exhaust to take place at given positions of the crank.

PROBLEM VII.

The lead, point of cut-off, and the amounts the ports are to be opened, for given positions of the crank, being determined, according to circumstances; to find the laps of the main valve and the respective throws of the main and expansion valve eccentric sheaves, and their positions relative to the centre line of the crank; and further, the dimensions of the steam-ports in the steam-chest being given, to determine the dimensions of the exhaust-port and of the various portions of the valves themselves.

This problem, as will be seen from the enunciation, embraces everything necessary for getting out a complete expansion gear with two slide-valves.

Draw *A B* and *C D* (Fig. 15) at right angles to each other, and let *F B* represent the assumed position of the crank at the commencement of the stroke. Set off *F Y* equal to the amount the port in the main valve is to be open, when the crank is in any particular position, such as *F W*. Draw *F E* in the direction in which the crank is to be, when the port in the main valve is just closed by the expansion valve, that is when the steam is just cut off. Through the point *F* draw *I J* at right angles to *F E*, and from the point *Y*, and at right angles to *F W*, draw *Y H*, meeting *F J* in the point *H*. Make *F K* equal to *F H*, and upon *F H* and *F K* as diameters describe circles; these will be respectively the primary and secondary

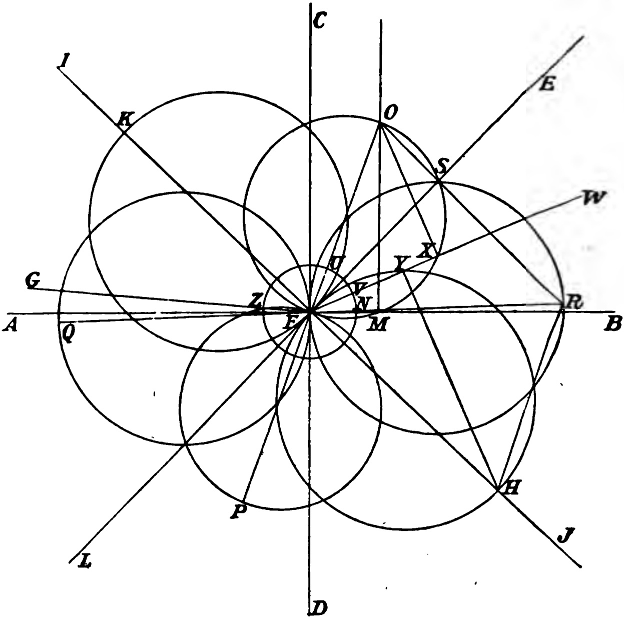


Fig. 15.

resultant circles. We shall now proceed to find the main valve circles, but before doing so must determine the amount of lap that the main valve is to have; this may in most cases be of the smallest amount, say one-eighth of an inch, when the line of the diameters of the resultant circles is taken at right angles to the direction of the crank at the point of cut-off, as in the present case. Otherwise, and when there is danger of the expansion valve reopening the port in the main valve before the latter has closed the port in the cylinder, determine the position of the crank, at which the expansion valve just commences to reopen the port in the main valve, and it is desirable that at this moment the main valve shall not only have fully closed the port in the cylinder, but shall also be overlapping it by at least one-eighth of an inch. We now proceed by either Problem III., or Problem IV., to find the required lap of the main valve, and the position and throw of its eccentric sheave; but in each of those problems we drew *C D* in the given direction of the crank, when the port was to be just closed and the steam cut off. Now, however, we draw *C D* (Fig. 16) in the direction in which the crank is when the expansion valve just begins to reopen the port in the main valve. From the point *C* (Fig. 16) set off *C E* equal to the given amount that the main valve is to overlap the port at the given position *C D* of the crank, and this amount, as we have just stated, should not be less, in ordinary cases, than about one-eighth of an inch. From the point *E* draw *E F* at right angles to the line *C D*, and through the point *A* draw *G H* perpendicular to *A B*, and cutting *E F* in the point *G*: set off *G F* equal to *G H*, and with the points *F* and *H* as centres, and with equal radii, describe arcs intersecting at any point *I*. Join *I G*. Then the centre of the crank-shaft, and hence the centre of revolution of the eccentric sheave, will lie somewhere in the line *I G*, and the centre of the eccentric

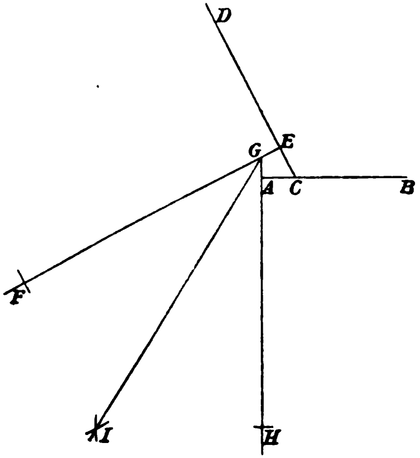


Fig. 16.

sheave itself will coincide with the point *C*; and this centre of revolution of the eccentric sheave in the line *I G* may be found as in Problem III., or as in Problem IV., according to which results are required to be obtained, for if we require the port in the cylinder to be open a given amount *at a certain* *position of the crank*, we proceed as in Problem III.; if, however, we only require that the *maximum* opening of the port shall be equal to a given amount, *without reference to the position of the crank at that moment*, we proceed as in Problem IV. But we almost invariably require in expansion gearing with two valves that at a given position of the crank the corresponding ports in the cylinder and main valve should be open a certain given equal amount; this will of course form the maximum steam passage; because, as the one port becomes more open, the other becomes more closed. This will be quite clear from the diagram, and the through passage of the two corresponding ports cannot be greater in area than the opening of the port which is the most closed. We have already constructed the resultant circles of our diagram (Fig. 15) so as to cause the port in the main valve to be open an amount equal to $F Y$ when the crank is in the position $F W$: we have now therefore only to obtain by Problem III. the throw of our main valve eccentric sheave, and its position with regard to the centre line of the crank, so that, besides giving the necessary lead and causing the valve to close the port in the cylinder at the required time, it shall cause the port in the cylinder to be open an amount equal to $F Y$ (Fig. 15) at the position $F W$ of the crank. In working out these required particulars it is desirable to make use of a separate diagram transferring to our expansion diagram the lap and main valve circles, otherwise the number of lines might make the diagram too confusing.

We will now revert to the case, in which, as we have already explained, we may safely *assume* the lap of the main valve, making it only just sufficient to close the ports securely, but even this is not absolutely necessary in *all* cases, as the combination may be so arranged that the main valve will close the port in the cylinder before the expansion valve reopens the port in the main valve, while the main valve itself has even what is termed *negative* lap, that is, the valve is shorter between its cut-off edges than the distance between the extreme edges of the two steam-ports; but it is better to take some *positive* lap for the main valve, otherwise when our figure is nearly complete we may find that the main valve closes the port too late, and have to entirely reconstruct the diagram from the beginning; for this reason we prefer to determine the particulars of the main valve by the direct method we just now explained as being quite certain, but when this is not done, and the lap of the main valve is determined arbitrarily, set this lap off from *F* to *N* (Fig. 15), and describe the lap-circle cutting *F Y* in the point *V;* set off the required lead from *N* to *M*, and at the point *M* erect a perpendicular. Now *F W* is the position of the crank at which it is required that the port in the cylinder shall be open an amount equal to *F Y;* set this distance off from to *X*. From the point *X*, and at right angles to *W*, draw *X O*, cutting the perpendicular *M O* in the oint *O*. Join *O F*; this will be the diameter of the rimary main valve circle, and will represent the hrow of the main valve eccentric sheave, and its osition with regard to the *real* position of the crank *A F*. Produce *O F* to *P*, making *F P* equal to *O F*. Upon *O F* and *F P* as diameters describe circles; these will be the primary and secondary main valve circles respectively, and whether we obtain these by this method, or by the previous and direct one, we next proceed in either case as follows. From the point *O* and through the point *S*, where the valve-circle *O X F* cuts the line *F E*, draw *O R*, this will be parallel to *F H*, and from the point *H* draw *H R* parallel to *F O*, and intersecting the line *O R* in the point *R*. Join *F R*; then will *F R* be the diameter of the primary expansion valve circle and represent the throw of the expansion valve eccentric sheave and its position with regard to the *real* position *A F* of the crank. Produce *R F* to *Q*, making *F Q* equal to *R F*. Upon *R F* and *F Q* as diameters describe circles, these will be the primary and secondary expansion valve circles respectively. We have now to decide upon the inside lap of the main valve, and as the method of doing this has been fully explained in Problem I., we need not do more than apply it to our present diagram, and to simplify matters we will assume that the exhaust is to open when the crank reaches the position *F G*. In this position the centre line of the crank cuts the secondary main valve-circle at the point *Z*, then *F Z* will be the inside lap of the main valve; but *F Z* is one of the radii of the outside lap-circle, and it represents the outside lap of the valve, therefore in the present instance the inside lap of the valve is made equal to the outside lap. Our diagram is now complete, and we will next proceed to show how to apply it to designing the slide-valves themselves, and the face of the ports in the steam-chest. We will take this latter first, and in the present case we will assume that the steam-ports are of the same length (measured always in the direction of the travel of the valve) as the throw of the eccentric sheave less the outside lap of the valve; thus *F O* (Fig. 15) represents the throw of the eccentric sheave, and hence half the travel of the valve. From this deduct the outside lap *F U*, and the remainder, *U O*, will in the present case represent the length of the steam-port.

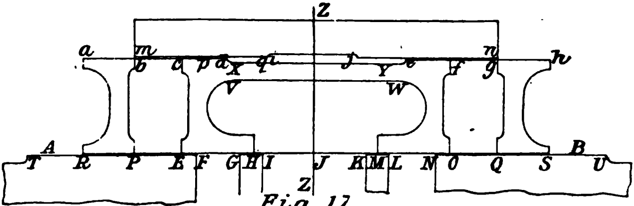


Fig. 17.

In the straight line *A B* (Fig. 17) take any point

E, and from this point set off *EF* equal to *FU* (Fig. 15), the outside lap of the main valve; then the point *F* will represent the outside edge of one of the steam-ports. From *F* set off *FG*, equal to the given length of the steam-port, measured as just explained. From *G* set off *GH*, equal to *FZ* (Fig. 15), the inside lap of the valve. From *G* also set off *GI*, the length of the bar dividing the steam from the exhaust port, this, as explained in Problem I., may be of any convenient length, provided it is sufficiently strong to resist the pressure of the steam and give a fair bearing surface for the valve to work upon; we will now take such a length for instance as one-half of the length of the steam-port *FG*. From the point *H* set off *HJ* equal to *FO* (Fig. 15), the half travel of the valve, and from the point *J* set off *JK* equal to *FG*, the length of the steam port. *IK* now represents the length of the exhaust port. From the point *K* set off *KL* equal to *GI*, this will represent the bar separating the exhaust from the second steam-port, and the point *L* will represent the inner edge of that port. From the point *L* set back the inside lap *LM* equal to *GH*. From *L* also set off the second steam-port *LN* equal to *FG*. From the point *N* set off the outside lap *NO*, equal to *EF*. From the points *E* and *O* respectively set off *EP* and *OQ*, each equal to *FG* or *LN*: these will represent the steam-ports in the main valve itself. From *P* and *Q* set off *PR* and *Q S* equal to each other; these will form the ends of the main valve, closing in the steam-ports which will thus pass through it, but these ends may be of any convenient length, provided they are of sufficient strength to resist the pressure of the steam and offer sufficient bearing surface on the faces. From the points *R* and *S* respectively set off *R T* and *S U*, each equal to *F O* (Fig. 15), the throw of the eccentric sheave equal to the half travel of the valve. Then *T U* will represent the total length of the port face in the steam-chest. We now proceed to determine the total thickness of the main valve, so as to be able to set out its upper face, upon which the expansion valve slides, but as the thickness of this main valve is regulated by the internal dimensions of the exhaust chamber within it, we must first set out this chamber itself. The length of this across the mouth is, as we have already shown, equal to *HM*, and its height should be at least equal to once-and-a-half the length of one of the steam-ports. At such a distance above the line *T U*, and parallel to it, draw the line *V W*, which will represent the top of the exhaust chamber; above this allow a sufficient thickness of metal, and draw the line *X Y*, this will represent the upper surface of the main valve; the face, however, upon which the expansion valve slides should be slightly raised above this; draw the line *a h* at say three-sixteenths of an inch above the top of the valve itself to represent this face. In the line *a h*, and at equal distances on each side of the centre line *Z Z*, set out the ports *b c* and *f g*, each equal in length to *P E* or *O Q*, and connected to the same respectively by passages through the valve; but to simplify matters we will take these ports as being vertical continuations of *P E* and *O Q*, slightly enlarging the passages, however, inside, so as to facilitate fitting up the working edges. We next proceed to design the expansion valve. Upon referring to the diagram (Fig. 15), we find that when the crank reaches the position, *F E*, at which the expansion valve has just closed the port in the main valve, that the expansion valve is at that moment in its central position on the back of the main valve, and as in that position its edges just, and only just, cover the ports in the main valve, it is quite clear that it can have no lap either positive or negative, and that its total length is exactly equal to *b g* (Fig. 17), the distance between the extreme edges of the two steam-ports in the upper face of the main valve.

We have now only to determine the lengths of the relative sliding surfaces of the two valves, and in doing this it is necessary to make the sliding surface, *c d* and *e f*, of such a length that they shall reach beyond the extreme point to which the end *m* or *n* of the expansion valve travels, otherwise the expansion valve might trip against the edge *d* or *e* on its return stroke. We must also take care that the points *i* or *j* in the expansion valve do not overshoot the edges *c* or *f* respectively of the ports in the upper face of the main valve. We find by the diagram (Fig. 15) that the length of half the travel of the expansion valve on the back of the main valve is represented by the line *K F*, that is, the expansion valve travels from its central position, *m n* (Fig. 17), on the back of the main valve an amount equal to *K F* in each direction. From *b* set off *b p* equal to *K F*, and beyond the point *p* allow a margin of safety *p d*, say of half-an-inch, or whatever circumstances may dictate, the point *d* will then represent the inner end of one of the upper sliding faces of the main valve; the length of *b a* may be determined by making it slightly less than *K F* (Fig. 15). To determine the length of the sliding face at the other end of the main valve, we have only to make *f e* equal to *c d*, and *g h* equal to *b a*. We next proceed to determine the lengths of the sliding faces, *m i* and *j n*, of the expansion valve. From *C* set off *C q* equal to *K F* (Fig. 15), the half travel of the expansion valve on the back of the main valve, and beyond the point *q* allow a margin of safety *q i*, say also of half-an-inch or whatever may be necessary, *m i* will therefore be the length of one of the sliding faces of the expansion valve. To find the length of the other face we have only to make *n j* equal to *m i*. The reason we place the line containing the diameters of the resultant circles at right angles to the position of the crank at which the cut-off takes place is that the expansion valve shall be in the middle of its travel on the back of the main valve at the moment of its cutting off the steam, as in this position the expansion valve is travelling at its highest speed on the back of the main valve, and relative to the same, thus it effects the sharpest cut-off. From this it will be clear that a valve to produce the sharpest cut-off should have no lap whatever, but in order to maintain this in such cases as when the cut-off is not to take place till the crank has arrived at some given position on the other side of *F O*, the diameter of the primary main valve circle, and when the main valve has changed its direction of motion we must construct the expansion valve with a port through it at each end, so that it shall still cut off the steam when it is moving in the reverse direction to the main valve, and we must then place the expansion eccentric sheave to *follow* that of the main valve, still bearing in mind that the *primary* resultant circle is the one that indicates the movement of the centre of the expansion valve to the *right* of that of the main valve. Our two valves are now complete as far as our present investigations are concerned, the question of connecting them up with the eccentrics being beyond the province of this treatise.

PROBLEM VIII.

The throw of the eccentric sheaves, the amount of lead, and the point of cut-off being given; to find the amount of lap for the main valve and the positions of the eccentric sheaves which will give the most rapid cut-off at the given position of the crank.

This is a problem that will frequently present itself to the engineer when making improvements in old engines, as in such cases the existing eccentrics will in all probability have to be used again. Draw *A B*, *C D* (Fig. 18) at right angles to each other and intersecting at the point *E*. With *E* as a centre and with radii equal to the throws of the eccentric sheaves respectively describe the circles *F K H* and *G B D*. The circle *F K H* will intersect the line *E B* in the point *K*. With this point as a centre and with a radius equal to the lead describe the lead circle. Determine the position of the crank at which it is required that the main valve shall just have closed the port in the cylinder, and to assist us in doing this correctly, draw through the point *E* the diameter *Q E L* touching the lead circle *L K* on the lower side: then the main valve should close the port in the cylinder before the crank reaches this position *Q E*, otherwise the valve would have negative lap, which for some reasons may be inconvenient; we therefore take such a position for the crank as *H E*, at which the main valve is to just close the port in

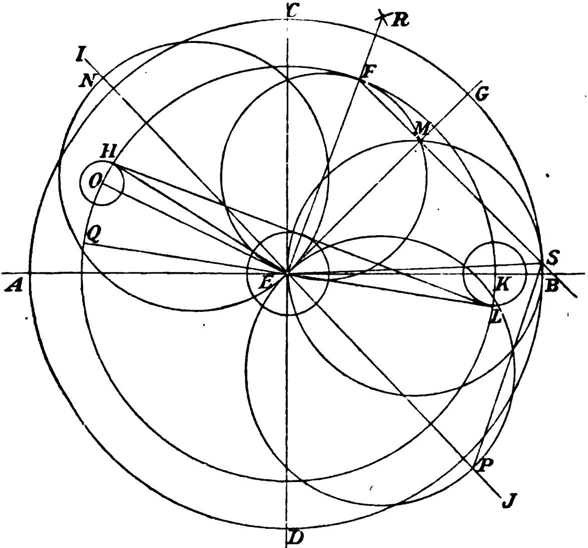


Fig. 18.

the cylinder. From *H* draw *H L* touching the lead circle *K L*, and cutting the circle *F K H* in the point *L*. With the points *H* and *L* as centres, and with any convenient radius describe arcs intersecting at *R*. Join *E R*, cutting the circle *F K H* in the point *F*;

then the line *E F* will be the diameter of the primary main valve circle, and will represent the position of the main valve eccentric sheave; with *E* as a centre, describe the lap-circle touching the line *H L*. Draw *E G* in the position the crank is required to be when the expansion valve just closes the port in the main valve, and cuts off the steam. Through the point *E* draw *I J* at right angles to *E G*. Upon *E F* as a diameter describe the primary main valve circle intersecting the line *E G* in the point *M*. Join *F M*, and produce it till it cuts the circle *G B D* in the point *S*. Join *E S*, then *E S* will be the diameter of the primary expansion circle, and will represent the position of the expansion-valve eccentric sheave with regard to the *real* position *A E* of the crank; upon *E S* describe the primary expansion valve-circle; from *S* draw *S P* parallel to *F E*, and cutting *E J* in the point *P*; make *E N* equal to *E P*, and upon *E P* and *E N* as diameters describe circles; these will be the primary and secondary resultant circles respectively.

Now suppose it is required that, when the crank has reached a given position, the main valve shall not only have closed the port in the steam-chest, but also be overlapping it by a fixed amount. Let *E O* (Fig. 18) be the given position of the crank: then with the point *O* as a centre, and with a radius equal to the given amount that the valve is to be overlapping the port for that position of the crank, describe a circle and draw *H L* as shown touching this circle and the lead circle *K*, and cutting the circle *F K H* in the points *H* and *L* respectively. Draw *E H* and *E L*. Then as before with the points *H* and *L* as centres, and with the same radius describe arcs intersecting at any point *R*. Join *E R*. From the centre *E* describe a circle touching the line *H L*; this will be the lap-circle, etc., etc.

From the explanation given in Problem II., it will be evident that when the crank reaches the position *O E* the valve will be overlapping the port by an amount equal to the radius of the small circle at *O*, which was made equal to the given amount. Now in the foregoing problem should it be required that the exhaust and compression should commence at given positions of the crank respectively, then we find the main valve-circles by Problem VI. (Fig. 14), and having done this we proceed to draw *E G*, etc., as already stated herein.

PROBLEM IX.

To find the position of the crank, at which the port in the main valve is open the same amount as the port in the cylinder.

Let the circles *O S F*, *R S F* and *F Y H* (Fig. 19), represent respectively the primary main valve circle, the primary expansion valve circle, and the primary resultant circle. Let *T V U* represent the lap-circle of the main valve. From the point *O*, the extremity of the diameter of the primary main valve circle, draw straight lines to the extremities of the diameters of the primary and secondary resultant circles, viz., to the points *H* and *K* respectively. From the point *F* draw *F G* parallel to *H O*, and intersecting *K O* in the point *Z*; with this point as a centre, and with a radius equal to *Z F* describe the circle *G S F*, which we will term the primary *differential* circle, or simply the *differential* circle, unless in special cases we may have to use the secondary one as well. This differential circle will cut the lap-circle in the point *V*; through this point draw *F V W*, which will represent the position of the crank when the port in the main valve is open the same amount as the port in the cylinder.

We will now proceed to explain the foregoing construction. It is quite evident from the diagram (Fig.

19) that when the crank is in the position *FM*, passing through the point *J*, where the primary main valve and resultant circles intersect, the main valve is the

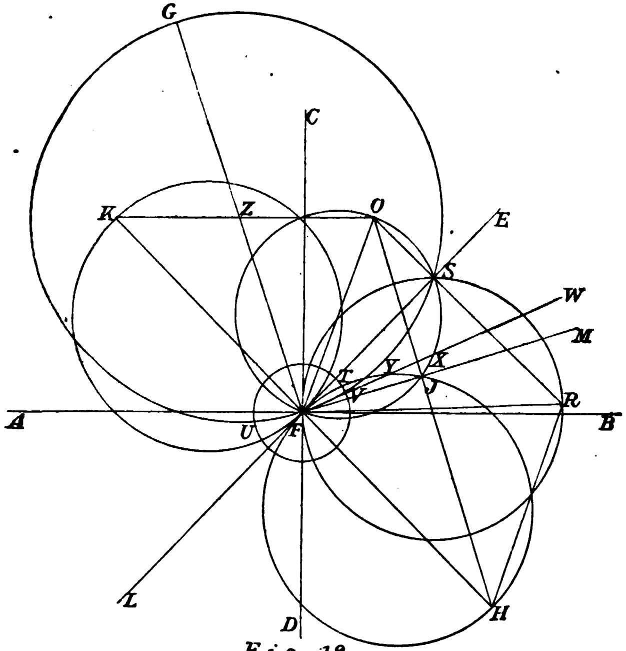


Fig. 19.

same distance to the right of its central position on the port-face, as the expansion valve is to the right of its central position on the back of the main valve. But the main valve must be a distance from its central position equal to its lap before it begins to open the port in the cylinder; and therefore to attain the distance it must be from its central position for the port in the cylinder to be open an amount equal to the amount the port in itself is opened by the expansion valve, it must have travelled from its central position through a distance just equal to its lap greater than the distance the expansion valve has travelled from the centre of the main valve. Now the circle described on the diameter *F G* represents by its radius vector the distance that the main valve is from its central position on the cylinder face greater than that which the expansion valve is from its central position on the back of the main valve; and in the position *F W* of the crank we find that the distance the main valve is from its central position, greater than that which the expansion valve is from its central position on the back of the main valve, is represented by the radius vector *F V*, which is also a radius of the main valve lap-circle, and is therefore equal to the lap of the main valve; hence in that position of the crank the port in the cylinder is open an equal amount to the port in the main valve. In cases in which the main valve has negative lap, or the expansion valve has any lap either positive or negative, we have only to describe a circle about the centre *F*, whose radius represents the distance the main valve has to be from its central position on the cylinder face, either greater or less than that which the expansion valve has to be from its central position on the back of the main valve, for the ports to be open an equal amount. It will be quite evident, therefore, that if neither valve has any lap, or if the expansion valve has a lap equal to the lap of the main valve, the difference in the distances they have to travel will vanish, and the port in the cylinder will be open an amount equal to the port in the valve, at the position *F M* of the crank, where its centre line passes through *J*, the point of intersection of the primary main and primary resultant circles. If, however, the positive lap of the expansion valve is greater than that of the main valve, we describe about the centre *F* the circle whose radius represents this difference of lap, and we produce the line *G F* to an equal distance on the other side of *F*, and describe the secondary differential circle upon it, touching the primary differential circle at the point *F;* and from this point, and through the point of intersection of the secondary differential circle and the small circle representing the difference of lap, draw a radius line: this will represent the position of the crank at which the port in the cylinder will be open an amount equal to that of the port in the main valve. From the preceding explanation it will be quite evident that we can vary the position of the crank at which the ports in the cylinder and in the main valve shall be equally open, and to do this it is only necessary to draw from the point *F* a radius line representing the position of the crank at which it is required that the ports in question shall be open an equal amount; and from the centre *F*, and through the point where this radius line intersects one of the differential circles, describe the lap circle, which will represent by its radius the difference between the laps of the main and expansion valves, or if the expansion valve is to have no lap, it will shew how much lap the main valve is to have, and whether positive or negative; and if the radius line, representing the given position of the crank, cuts the primary differential circle, then the lap of the main valve will be positive, and if it cuts the secondary differential circle, then the main valve will have negative lap. Care must be taken, however, not to alter the lap of the main valve beyond the limits laid down to meet the other requirements of the expansion gear; and it is most undesirable to give the expansion valve any lap, either positive or negative, as it would injuriously affect the sharpness of the cut-off, the valves being at their highest relative velocities when the crank is in the position *FE*, at right angles to the diameters of the resultant circles, and in this position of the crank the cut-off should therefore take place; but were there any lap on the expansion valve, either positive or negative, the cut-off would take place either before or after the crank had reached this position, and would not therefore be so rapid.

PROBLEM X.

The position of the centre line of the resultant circles, the amount the ports in the main valve are to be open at any particular position of the crank, and the position of the crank itself at which the cut-off is to take place, being given; to find the length of the diameters of the resultant circles, and the amount of lap required to be given to the expansion valve.

In expansion gearing, in which the expansion valve has a positive lap, or in the case of variable expansion gearing, in which the expansion valve has a varying lap imparted to it, and which lap is made to increase as an earlier cut-off is required, it is most essential that care should be taken to see that this lap does not absorb too much of the travel of the expansion valve relative to the main valve, or the port in the main valve will not be sufficiently opened for the admission of steam. To take an extreme case, were the lap of the expansion valve made equal to the travel of the valve itself, from its central to its extreme position, then it is quite evident that the port would not be opened at all. It is necessary therefore when designing valve gear to determine upon that position of the crank at which the earliest cut-off is required to take place, and then proceed as follows:—

Draw *A B* (Fig. 20) to represent the (assumed) position of the crank at its dead-point, and *A Y* to represent the centre line of the resultant circles, that is, the line containing their diameters; and draw *A Z* to represent the position of the crank, at which the earliest cut-off is to take place, and *A L* to represent the position of the crank, at which the port in the main valve is to be open the given amount. Upon the line *A Z* set off *A T* equal to this amount. From the point *T* draw *T P* perpendicular to *A Z*. From the point *A* draw *A M* perpendicular to *A L*,

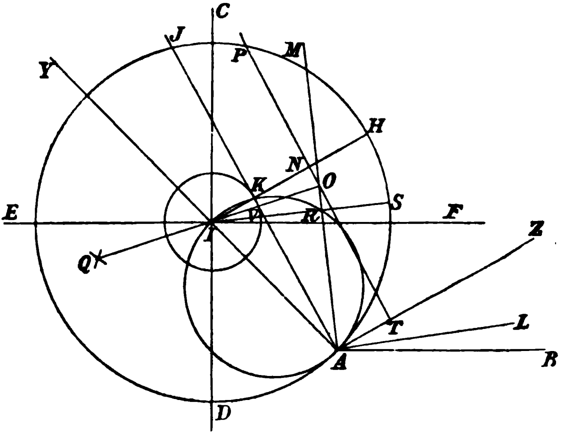


Fig. 20.

and cutting *T P* in the point *O*. Set off *O P* equal to *O A*, and, from the points *P* and *A* as centres and with the same radius, describe arcs intersecting at any point *Q*, join *Q O*, cutting *A Y* in the point *I*, then will this point *I* represent the centre of the crank shaft, and *I A* the diameter of the primary resultant circle. From *A* draw *A J* parallel to *T P*, and with the point *I* as a centre, describe a circle touching the line *A J* at the point *K*; this circle will be the lap-circle, and its radius *I K* will represent the lap of the expansion valve. Upon *I A* as a diameter describe the primary resultant circle; and with the point *I* as a centre, and with a radius *I A*, describe the circle *A S J*. From the point *I* draw *I S* parallel to the given position *A L* of the crank, and *I H* parallel to the given position *A Z* of the same. *I S* will now represent the given position of the crank, at which it is required that the port in the main valve should be open the given amount, and *I S* is intersected at the point *R* by the resultant circle, and at the point *V* by the lap-circle, hence at this position of the crank the port in the main valve is open an amount *V R*, which can be readily shown to be equal to *K N*, and *K N* to *A T*, which was made equal to the required amount that the port was to be open. Similarly *I H* will now represent that position of the crank at which it is required that the cut-off shall take place, and it passes through the point of intersection of the lap and resultant circles, hence at this position of the crank the port in the main valve is just closed by the expansion valve and the steam cut off. Through the point *I* draw *E F* parallel to *A B*, and *C D* at right angles to it. *I F* will now represent the assumed position of the crank, which *A B* was made originally to represent.

Our diagram is now complete, and we obtain from it the proper diameters for the resultant circles, and proceed to construct our expansion gear diagram (Fig. 21) accordingly.

VARIABLE EXPANSION GEARING.

PROBLEM XI.

The positions of the crank, at which the exhaust is to be opened and closed respectively, the amount of lead and the amount the ports are to be opened for a certain position of the crank being given; to find the positions and throws of the eccentric sheaves and the laps of the main valve. Also the dimensions of the steam-ports in the steam-chest being given; to determine the dimensions of the exhaust port and of the various portions of the valves themselves. And any positions of the crank, at which the steam is to be cut off by the expansion valve being given, to ascertain the amount of positive or negative lap (if any) which must be given to the expansion valve at each of those positions.

We first proceed by Problem VI. to find the position and throw of the main valve eccentric sheave, the position of the crank at which the main valve closes the port in the steam-chest, and the external and internal laps of the main valve. Having done this, we draw AB and CD (Fig. 21) at right angles to each other, and intersecting at the point *E*. Draw *EH* to represent the position, and throw of

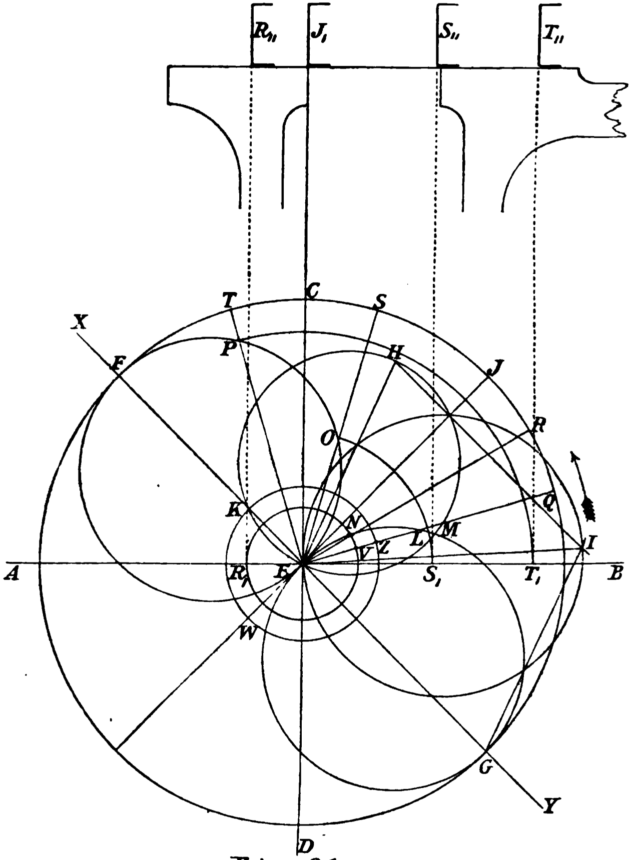


Fig 21

the main valve eccentric sheave, relative to the *real* position AE of the crank, as just ascertained by Problem VI., and similarly draw EX to represent the position of the crank when the main valve closes the steam-port in the steam-chest; and with the point E as a centre, and with a radius equal to the ascertained external lap of the main valve describe the lap-circle KZW. Produce the line XE beyond the point E to any point Y, then the line XY will represent the position of the centre line of the resultant circles. Let ER represent the position of the crank at the earliest point of cut-off of the expansion valve, and let EQ be the position of the crank at which it is required that the corresponding ports in the steam-chest, and in the main valve, shall be open the given amount. Next, by Problem X., we ascertain the length of the diameters of the resultant circles, and the amount of the lap (if any) of the expansion valve, so that the port in the main valve shall be first opened the required amount, and then closed, and the steam cut off at the given positions of the crank respectively. Set off EF and EG to represent these diameters as just ascertained, and upon these describe the primary and secondary resultant circles GLE and EPF, and if the expansion valve is to have any lap, from the centre E, and with radius equal to this lap, as ascertained by Problem X., describe the lap-circle $VNR_{\prime}$, passing through the point of intersection, N, of the primary resultant circle $G L E$, and the centre line, $E R$, of the crank.

Let $E R$, $E S$, and $E T$ represent the several given positions of the crank, at which it is required that the expansion valve can be adjusted to cut off the steam. The line $E R$ cuts the primary resultant circle in the point N, and the lines $E S$ and $E T$ will cut the secondary resultant circle in the points O and P respectively. From the centre E, and with distances $E O$ and $E P$ respectively as radii, describe arcs cutting the line $E B$ in the points $S_{,}$ and $T_{,}$. Now, for reasons similar to those already explained with reference to plain valve gear (p. 16), when the centre line of the crank cuts the *primary* resultant circle, $E N G$ (Fig. 21), it demonstrates that the expansion valve is to the *right* of its central position, relative to the main valve, but when it cuts the *secondary* resultant circle, $E P F$, then it demonstrates that the expansion valve is to the *left* of such central position, the amount it has travelled from that position in each case being represented by the length of the radius vector on such centre line of the crank, and when this centre line coincides with the diameter of either the primary or secondary resultant circle, it demonstrates that the expansion valve is correspondingly either to the extreme right or to the extreme left of its central position relative to the main valve, and, as shown in our diagram (Fig. 21), the crank, after passing the position $E G$, moves towards $E F$, that is away from the position at which the expansion valve is to the extreme right of its relative travel, and towards that position at which the expansion valve will be to the extreme left of such travel; hence, after the crank has passed the position *E G*, the expansion valve is moving from right to left relative to the main valve, and it reaches its central position, relative to the same, when the crank arrives at the position *E J*, at right angles to the diameters of the resultant circles, and in this position the centre line of the crank does not therefore cut either of the resultant circles. Now, starting from the dead-point *E B*, we are first, as we have just shown, considering the motion of the expansion valve from right to left relative to the main valve; hence, to effect the cutting off of the steam when the expansion valve is moving in this direction, we have to deal with that end of the valve, which is to the left, as shown at the upper part of our diagram, where the expansion valve is supposed to be in its central position on the back of the main valve as drawn at $J_{\prime}$, with no lap either positive or negative, but at $R_{\prime\prime}$ with positive lap, and at $S_{\prime\prime}$ and $T_{\prime\prime}$ with negative lap. Now, taking the expansion valve with no lap as at $J_{\prime}$, and supposing it is required that it shall close the port in the main valve, and cut off the steam when the centre line of the crank is at the position *E R*, at which it cuts the primary resultant circle in the point *N*, showing that the valve is still to the right of its relative central position an amount equal to *EN*; and as we are supposing it to have no lap, it is quite evident that in this position it leaves the port in the main valve still open an amount equal to *EN*. In order, therefore, to cause the port in the main valve to be just closed by the expansion valve at this position of the crank, we must extend the edge of the expansion valve to the left by an amount equal to *EN*, that is, we must give it a positive lap of this amount; and to do this conveniently, by our diagram, we draw a full-size section of that end of the main and expansion valves under consideration, and in such a position that the line *CD* produced just passes along the cut-off edge of the port and the left end of the expansion valve, when it has no lap. Hence, when the cut-off is to take place before the expansion valve reaches its relative central position, we have to give it a positive lap equal to the amount it has yet to travel before it reaches that position; and to do this we have only to set off the required amount of positive lap from *E* towards *A*, and erect a perpendicular at that distance from the point *E*; this perpendicular will determine where the left edge of the expansion valve position relative to the main valve. Thus, when it is to come to when the valve itself is in its central is required that the expansion valve shall just close the port in the main valve when the crank reaches the position *ER*, intersecting the *primary* resultant circle, ELG, at the point N, showing that a positive lap equal to EN is required for the left end of the expansion valve, we have to set this distance off from E to R_1, and this is most conveniently done by taking the point E as a centre, and with radius EN describing an arc NR_1 (which in our diagram (Fig. 21) will form a portion of the lap circle VNR_1), intersecting AB in the point R_1, to the *left* of the centre E, because we are now considering the travel of the expansion valve from right to left, and positive lap is always set off in the direction towards which the valve is relatively travelling, it being understood that we are at the same time dealing with the edge of the valve which is towards that direction. Now, supposing it is required that the expansion valve shall not close the port in the main valve till the crank reaches the position ES, in this position its centre line cuts the *secondary* resultant circle in the point O, demonstrating that the expansion valve is now to the *left* of its relative central position an amount equal to EO. Now, had this valve no lap, either positive or negative, it would have closed the port in the main valve when the crank reached the position EJ; therefore, when the crank reaches the position ES, the expansion valve would be overlapping the port by an amount equal to EO. Hence to cause the expansion valve to only just close the port in the main valve, when the crank reaches this position ES, we must cause the edge of the expansion valve to recede an amount equal to $E O$, but without altering the position of the centre line of the valve, that is, we must give the expansion valve a negative lap equal to $E O$; and to set this out in our diagram we have only to set off from E towards B an amount $E S_{,}$ equal to $E O$, and at the point $S_{,}$ to erect a perpendicular which will determine where the left edge of the expansion valve is to come to when the expansion valve itself is in its central position relative to the main valve. Now the most convenient method of setting off $E S_{,}$ is, as we similarly explained just now, to take the point E as a centre, and through the point O to describe an arc cutting the line $A B$ in the point $S_{,}$ to the right of the centre E. And we proceed in like manner for any other position of the crank at which it is required that the cut-off shall take place, bearing in mind always that when the crank is passing through that half of its revolution in which the expansion valve is travelling from right to left relative to the main valve—such, for instance, as when the crank is passing from $E G$ round to $E F$—then we have to deal with the left end of the valve; and when, under these circumstances, the centre line of the crank cuts the *primary* resultant circle, the arcs described through these points of intersection are made to intersect the line $A B$ to the *left* of the centre E; but when the centre line of the crank intersects the *secondary* resultant circle, then the arcs described through the points of intersection are made to intersect the line *A B* to the *right* of the centre *E*.

We determine the proportions of the other portions of the valves in the same manner as in Problem VII., except that we must take into consideration the extreme positions of the two halves of the expansion valve, which are constructed so as to be brought nearer together towards the centre when *negative* lap is required, and to be extended in the opposite direction when *positive* lap is needed. This is brought about in a variety of ways, which it is beyond the scope of the present treatise to describe.

EXPANSION GEARING.

PROBLEM XII.

Given the throw and position of the main valve eccentric sheave, the lap of the expansion valve and the positions of the crank, viz. that in which the port in the main valve shall be open a certain fixed amount and any position in which it shall just be closed and the steam cut off. It is required to find the throw and position of the expansion valve eccentric sheave.

Draw *A B*, *C D* (Fig. 22) at right angles to each other and intersecting at the point *E*, and draw *E F* to represent the throw and position of the main valve eccentric sheave. From the centre *E* and with a radius equal to the lap of the expansion valve, whether positive or negative, describe the lap-circle *K M N*. Draw *E G* to represent any position of the crank when the steam is to be cut off and, if the lap be positive, from the point *K*, where this line *E G* intersects the lap-circle, draw *K O* perpendicular to *E G*, but if the lap of the expansion valve be negative, produce *G E* till it again cuts the lap-circle in the point *N*, and from this point draw *NR* perpendicular to *GN*. We then in either case proceed to draw *EH* to represent the position of the crank when the port in the main valve is to be open the given

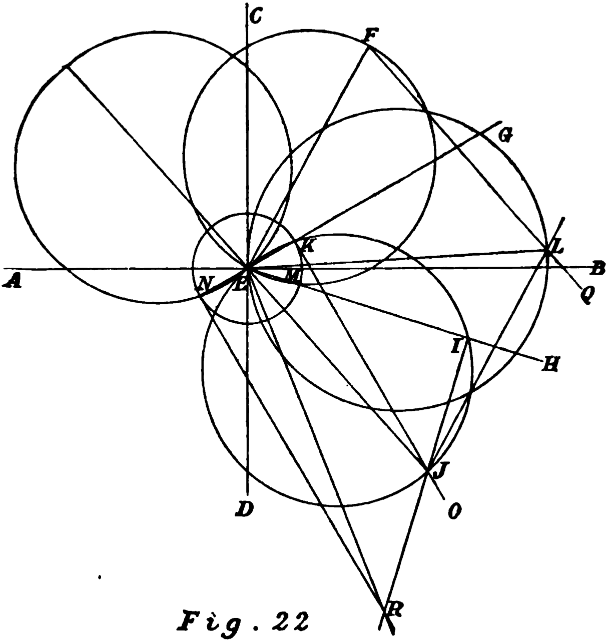


Fig. 22

amount, and from the point *M*, where it intersects the lap-circle, set off *MI*, equal to this amount. From the point *I* draw *IJ*, perpendicular to *EH* and intersecting the perpendicular drawn either from the point *K* or the point *N* in the point *J* or *R*. Join *JE* or *RE*, as the case may be, this line will then be the diameter of the primary resultant circle. From the point *F* draw *FQ* parallel to this diameter, and from the point *J* or *R* draw a line parallel to *EF* and intersecting the line *FQ* in the point *L*. Join *EL*, this will be the diameter of the primary expansion circle, and it will represent the throw and position of the expansion eccentric sheave, which was required to be found.

We have completed the diagram (Fig. 22) for the case of the positive lap only, this is done in order to save a confusion of lines.

PROBLEM XIII.

Given the throw and position of the main valve eccentric sheave, and the positions of the crank; viz. that in which the port in the main valve shall be open a certain fixed amount, and any position in which it shall just be closed and the steam cut off. It is required to find the throw and position of the expansion valve eccentric sheave.

In this case the expansion valve is assumed to have no lap either positive or negative, we therefore proceed as follows.

Draw *A B*, *C D* (Fig. 23) at right angles to each other, intersecting at the point *E*, and draw *E F* to represent the throw and position of the main valve eccentric sheave, and upon this line as diameter describe the primary main valve circle. Draw *E G* to represent any position of the crank at which the steam is to be cut off from the cylinder; and *E H* to represent its position when the port in the main valve is to be open the given amount. From *E* set off on *E H*, the amount *E I*, equal to the given amount. From the point *I* draw *I O* perpendicular to *E H*. From the point *F*, and through the point *K*, where the primary main valve circle intersects the given line *E G*, draw the line *F M;* and from the point *E* draw the line *E N* parallel to *F M*, intersecting the line *I O* in the point *J*. Then *E J* will represent the diameter of the resultant circle. From the point *J* draw *J P* parallel to *E F*, intersecting the line *F M* in the point *L*. Join *E L*, this will be the diameter of the primary expansion circle and will represent the relative position and the throw of the expansion valve eccentric sheave, which was required to be found.

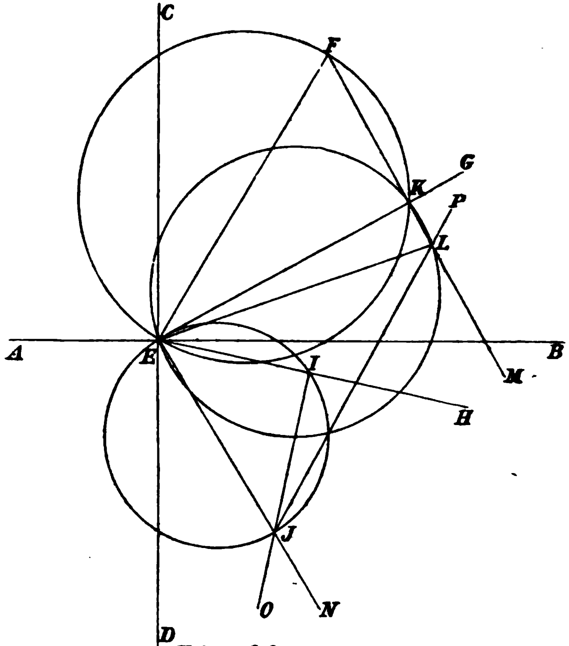


Fig. 23.

VARIABLE EXPANSION GEARING.

PROBLEM XIV.

Given the throw and position of the main valve eccentric sheave, the throw of the expansion sheave, the lap of the expansion valve, and any position of the crank, at which the expansion valve shall close the port in the main valve and cut off the steam. It is required to find the position of the expansion eccentric sheave.

Draw *A B*, *C D* (Fig. 24) at right angles to each other, intersecting at the point *E*. Draw *E F* to represent the throw and position of the main valve eccentric sheave. Produce *F E* to *G*, making *E G* equal to *E F*. Upon *E F* and *E G* as diameters describe circles: these will be the primary and secondary main valve circles. From the point *F* as centre, and with a radius equal to the lap of the expansion valve, whether positive or negative, describe the lap-circle *I L K*. From the centre *E*, and with a radius equal to the throw of the expansion eccentric sheave, describe the circle *M C N P*. Let *E Q* represent any position of the crank at which it is required that the steam shall be cut off by the expansion valve; at right angles to *E Q* draw a line touching the circle *I K L*, and cutting the circle *M C N P*. Now, if the expansion valve has positive lap, this line will be drawn touching the lap-circle on that half of its circumference farthest from the centre of the figure, as at *L O*, but if the lap of the expansion valve be negative, then the line will be

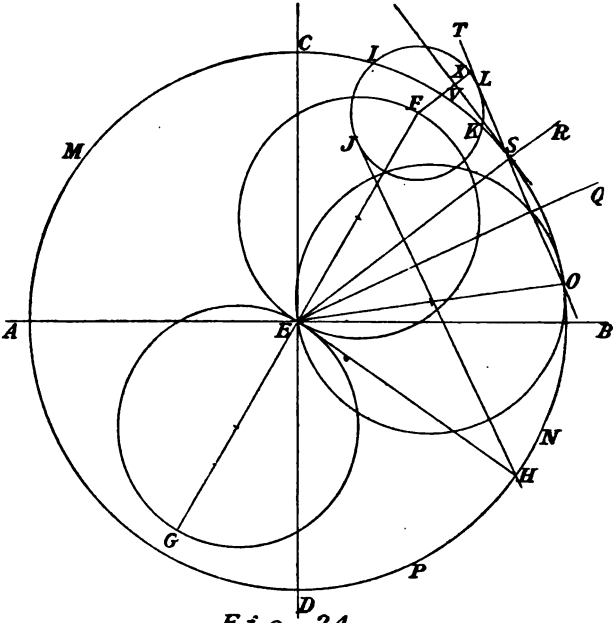


Fig. 24

drawn touching the lap-circle on that half of the circumference which is towards the centre of the figure, as at *JH*. Next join *EO* or *EH*, as the case may be, and this line *EO* or *EH* will be the diameter of the primary expansion circle, and will represent the position of the expansion eccentric sheave, which was required to be found. We also ascertain from this problem that when the expansion valve has positive lap, the difference between the throws of the two eccentric sheaves should never be less than this lap, for were we wanting to cut off the steam for such a position of the crank as *ER*, we find that we cannot draw the line *TS* at right angles to *ER* so as to touch the lap-circle, and to cut or even touch the circle *MCNP* at the same time; but if this line is drawn to touch the circle *MCNP*, it will cut the radius, *FX*, of the lap-circle in the point *V*, showing that either the lap of the expansion valve must be reduced, or the throw of its sheave increased by an amount equal to *VX*. If, again, we want to cut off the steam in such a position of the crank as *EF*, we should then find we should have to either reduce the lap of the expansion valve, so that it was exactly equal to the difference in the throws of the two eccentric sheaves, or we should have to increase the throw of the expansion eccentric sheave, so as to make the difference between the throws of the two sheaves exactly equal to the lap of the expansion valve.

It will be seen from the foregoing that when the expansion sheave is arranged so that its angular position can be altered with regard to the crank, this combination becomes a Variable Expansion Gear, and this may be done in several ways, and so as to be adjusted either by hand or by the governor.

EXPANSION GEARING WITH DOUBLE STEAM-CHESTS.

PROBLEM XV.

Given the relative positions of the crank, at which the exhaust is to be opened and closed respectively, the amount of lead, the amount the ports are to be opened for a certain position of the crank, and the position of the crank itself, at which the steam is to be cut off. To find the positions and throws of the eccentric sheaves, and the laps of the valves.

We have hitherto been treating of expansion gearing in which the cut-off valve slides on the back of the main valve itself, we have now to deal with an arrangement of expansion gear in which the steam-chests are divided into two chambers, in the outer one of which the cut-off valve works upon a face formed on the surface of the dividing plate. The disadvantage of this arrangement is that the steam which is in the inner chamber when the cut-off takes place participates in the expansion that goes on in the cylinder until the main valve closes the cylinder port. In designing a complete valve gear on this principle we have simply to treat the two valves quite separately, but for the sake of comparing the movements we find it convenient to unite the two diagrams in one, and, as in the previous cases, in which the expansion valve does the cutting off of the steam, we can place the main valve eccentric sheave in such a position as will cause the valve to open and close the exhaust port at given positions of the crank, thus causing the exhaust and compression to commence at those positions respectively. We now proceed by Problem VI. to find the position and throw of the main valve eccentric sheave and the laps of the main valves. This being done we next obtain similar particulars with regard to the cut-off or expansion valves by the first part of Problem VII., in which we have shown that the sharpest cut-off is effected when the diameters of the expansion circles are at right angles to the given position of the crank at which the cut-off takes place, and the expansion circles in the present problem correspond to the resultant circles in the problem referred to. We now transfer the results thus obtained by Problems VI. and VII. to a single diagram (Fig. 25), where the circles *D M K* and *K W F* are the main valve circles obtained by Problem VI., and the circles *U M X* and *ab* are the lap-circles of the same, and the circles *K Q J* and *K X I* are the expansion circles as obtained by Problem VII. Then with centre *K* and radius *K E* we describe the circle *E H A*, and draw *Y K* and *Z K* to represent the positions of the crank at which the exhaust is to be opened and closed respectively, and *K B* to represent the position of the crank at its dead-point *B*. Produce *B K* to *A*. Draw *K C* to

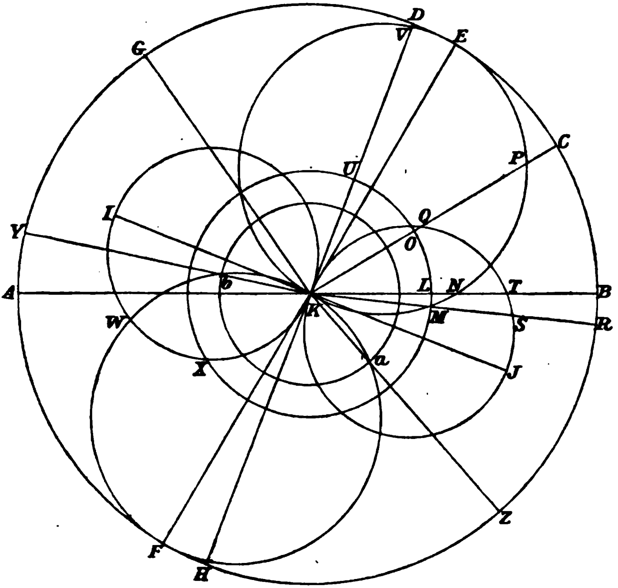


Fig. 25.

represent the position of the crank at which the port is to be opened the given amount, and *K D* to represent its position when the expansion valve is to close the port in the partition, and cut the steam off from the inner chamber of the valve chest, and hence from the cylinder. Through the points *a* and *b*, where the centre lines *YK* and *ZK* intersect the secondary main valve circle, describe the internal lap-circle. If we now examine this combined diagram (Fig. 25) we shall find that in the position *KR* of the crank, the port in the partition is open an amount *KS*, while that in the cylinder is only just about to commence to open; and when the crank reaches the dead-point *KB*, and the piston is about to commence another stroke, the port in the cylinder is open an amount *LN*, which is therefore the lead, and this was made equal to the required amount of lead by Problem VI. Taking next the position *KC* of the crank at which it was required that the port in the partition and the port in the cylinder, should each be open the given amount, we find that *OP* represents the amount the cylinder port is open, and *KQ* the opening of the port in the partition, and these are equal to each other and to the given amount of opening as they have been made so by Problems VI. and VII. respectively. Next, when the crank reaches the given position *KD*, at right angles to *IJ*, in which position of the crank the steam is to be cut off, we find that the expansion valve has reached its central position, and, having no lap, it has just closed the port in the partition and cut off the steam from the inner chamber of the steam-chest; but the main valve does not close the port in the cylinder till the crank reaches the position *KG*;

so that while the crank is travelling round from the position *K D* to *K G*, the steam contained in the inner chamber of the steam-chest participates in the expansion which is going on in the cylinder, and this is not desirable. In the foregoing we have assumed that the main steam-chest is in two separate parts, one at each end of the cylinder, so that the expansion valve, passing its central position, and reopening the port in the partition leading into the main steam-chest at one end of the cylinder, does not affect the end where the cut-off has just taken place. In cases in which the main steam-chest is in one, having the expansion valve working upon a partition in the same, it becomes necessary to obtain the particulars for the expansion sheave and valve by a different form of construction (see p. 216), as we have to arrange the various parts so that the expansion valve, having closed the port in the partition at one end, shall not begin to open the port at the other until the main valve has also closed the cylinder port at the former end. We need not go further into the matter here, but any other particulars we may require can be obtained from the combined diagram.

LINK-MOTIONS.

We have hitherto been treating of valve-gears, in which the valves have been driven direct from the eccentrics; we will now proceed to consider combinations termed *link-motions* in which the movements of the eccentrics are first imparted to an intermediate portion of the mechanism termed the *link*. In link *reversing* gears there are two eccentrics to each valve, the one is set for the *forward* and the other for the *backward* motion of the engine, and the two rods are attached one to each end of the link, which consists of a short bar, throughout the length of which is a slot or its equivalent, in which a slider, attached either directly or indirectly to the valve-spindle, is fitted; the principle of the arrangement being that the slider can be made to occupy any position in the link either by moving the link itself, the slider remaining still, as in Stephenson's link-motion, or by moving the slider while the link remains still, as in Gooch's arrangement, or again by moving both link and slider, but in opposite directions, as in Allan's link-motion. However, it matters not by which arrangement the positions of the link and slider, relative to each other, are altered, the result being practically the same, and what we have to investigate is this:—Given the throws and positions of the eccentric sheaves, the lengths of the eccentric rods, and the length of the link (measured always from centre to centre of the pin-holes where the eccentric rods are attached), to find what motion will be transmitted to the valve for each position of the link relative to the slider; and although the result is influenced by other considerations, such as the mode of suspending or supporting the link and slider so as to maintain them in their relative positions, for the present we will assume that these are so arranged as practically not to affect it; there is, however, one other point we require to take into account, viz., whether the eccentric rods are to be "open" or "crossed;" that is, the crank being at its dead-point furthest from the link, are the eccentric rods to be open (Fig. 26), or are they to cross each other (Fig. 28)? And with regard to the position of the slider in the link, we would here explain that when it occupies a position at either extreme end of the link, so that its centre becomes concentric with that of the eccentric rod end, and the valve-spindle is moved by the eccentric rod as if no link were intervening, then the link is said to be in *full forward* or *backward gear,* as the case may be; and when it occupies a position midway between the extreme positions, the link is said to be in *middle gear;* but when it occupies any other position in the link, then the link is said to be in *intermediate gear.* Some links, however, do not admit of the slider being brought into a position that places the eccentric rod virtually into direct gear with the valve-spindle, and in these full forward or backward gear is understood to mean the nearest approach to that position which the particular form of link will admit of. We will now proceed to investigate the various forms of link-motion in general use; and in doing so it must still be remembered that when we speak of the position of the crank we invariably mean its *assumed* position, unless in any particular case we state that it is to its *real* position that we are referring. The *assumed* position of the crank, as we have already explained (p. 10), is at the same angular distance from the one dead-point that its *real* position is from the other, but is set off in the opposite direction to that in which the real crank revolves.

STEPHENSON'S LINK-MOTION.

This form of link-motion is the one which is most commonly met with in practice. It consists of the arrangement to which we have alluded, in which the link is moved relative to the slider, while the slider itself has only a motion backwards and forwards in the direction of the valve-spindle. The link is curved to a radius equal to the length of one of the eccentric rods, and has its concave side towards the eccentric shaft; this length of the eccentric rods is, of course, measured from the centre of the strap that embraces the sheave to the centre of the pinhole where the rod is attached to the link. We will first consider a case with open rods.

In the vertical line *A B* (Fig. 26), representing the direction of the valve-spindle, take a point *C* to represent the centre of the crank-shaft, and draw *C D* and *C E* to represent the throws and positions of the eccentric sheaves relative to the position *CB* of the crank, from the point *C* as a centre, and with radius *C D* or *C E* describe the circle *D E B.* From the points *D* and *E* respectively as centres, and with a radius equal to the length of the eccentric rods

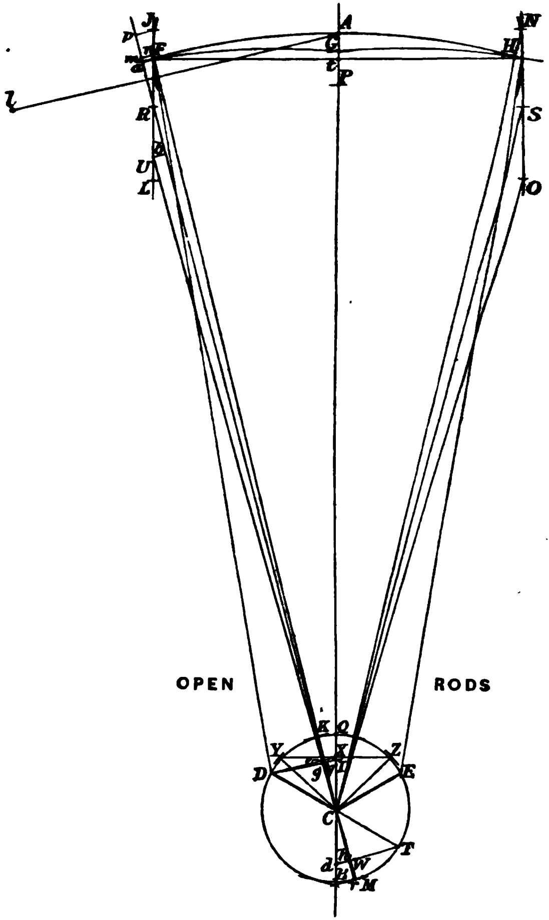


Fig. 26.

measured as just now explained), describe the arcs *F G* and *G H* intersecting at the point *G*. From this point as centre, and with a radius equal to half the length of the link, describe the arcs at *F* and *H*, and draw the lines *J L* and *N O* each parallel to *A B*, touching these arcs, and intersecting the arcs *G F* and *G H* in the points *F* and *H* respectively. From *F* and *H* as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting in the point *I*, and from this point as a centre, and with the same radius as before, describe the arc of the link *F A H*. Join *F D* and *H E*, then these lines will represent the eccentric rods. Upon the lines *J L* and *N O* set off the length of the travel of the points *F* and *H* respectively, as the travel of both these points for the position of the link given in the figure will be greater than merely twice the throw of the eccentric sheaves, but if the link be moved so that the valve is in full gear either way, then the point *F* or *H* falling in the straight line *A B*, the travel of that point will be exactly equal to twice the throw of the eccentric sheave *C D* or *C E*, but at the same time the other point will be further still from the centre line *A B*, and will travel through a distance still greater than it did when the link was in middle gear; to set off, therefore, upon *J L* and *N O*, the travel of the points in question, we proceed as follows; in the line *J L* find such a point *J*, as centre, that an arc described from it with a radius equal to the length of the eccentric rods will touch the circle *DEB* at any point *K*, on the side nearest to the link; and in the same line *JL* find another point *L* as centre, so that an arc described from it with the same radius as before will touch the circle *DEB* at any point *M* on the side furthest from the link, then the distance *JL* will represent very approximately the travel of the point *F* in a direction parallel to *AB*, in the same manner the travel of either end of the link may be found, whatever position the link itself may occupy relative to the slider; and we should so proceed to find the travel of the other end *H*, but as the link in the present case is set in middle gear and both eccentrics have the same throw, the end *H* will have the same travel as the end *F*, and we have, therefore, merely to set off this travel upon *NO* in a similar manner to that in which it is set off on *JL*. There is a simpler way of setting off the travel of the ends of the link. Take the point *J*, for instance, which was fixed upon as being such a point that an arc described from it as centre, and with a radius equal to the length of the eccentric rods, would just touch the circle *DEB* at the point *K*; the distance *JK*, therefore, is equal to the length of the eccentric rods, and the distance *KC* is a radius of the circle *DEB*, the whole distance *JC* is, therefore, the length of one of the eccentric rods *plus* the radius of the circle *DEB*. In the same manner we can how that the whole distance, LC, is equal to the ength of one of the eccentric rods *minus* the radius f the circle DEB; we can therefore set these disances off direct from the centre C. From this entre set off, on the line CA, the distance CP qual to the length of one of the eccentric rods; hen from the point C as a centre, and with a radius equal to BP, describe arcs cutting JL and NO in the points J and N respectively, and from the same centre, and with a radius equal to QP, describe arcs cutting JL and NO in the points L and O respectively; then the distance JL will represent, as before, the travel of the end F of the link, and the distance NO will represent the travel of the end H, both eccentric sheaves being of the same throw, equal to the diameter of the circle DEB. Bisect JL and NO in the points R and S respectively. Join RC and SC, these lines will, in practice, pass almost exactly through the dead-points of the eccentric sheaves. Join FC. From the point F as centre, and with a radius, FD, equal to the length of the eccentric rods, describe from the point D the arc DV, cutting FC in the point V. Produce DC to T, and from the point T as centre, and with a radius, as before, equal to the length of one of the eccentric rods, describe an arc cutting JL in the point U. Join UC, producing it till it again meets the circumference of the circle DEB, and from the point U as a centre, and with a radius also equal to the length of one of the eccentric rods, describe from the point *T* the arc *T W*; then if we assume that the point *F* has just been travelling in the direction *C F*, the distance *C V* will represent the amount that that point has already travelled from its central position on the line *F C*, when it occupies the position at *F*. Similarly assuming that the point *U* travels in the direction *U W*, then *C W* will represent the distance the point *U* has already travelled from its central position in the direction *U C*, when it occupies the position at *U*. Now the length of the arc *T W* is less than that of the arc *D V*, because the angle *T C W* is less than the angle *D C V*, by an amount equal to the angle *U C F*; therefore the versed sine of the arc *T W* is less than the versed sine of the arc *D V*. Now we have already shown that the line *R C* almost exactly passes through the dead-points of the eccentric sheaves; if, therefore, we take this line as a mean, and produce it till it meets the circumference of the circle *D E B* in the point *r*, and continue the arc *T W* till it meets it in the point *h*, then the arc *T h* will be equal to the arc measured from the point *D* to the point *g*, where the arc *D V* intersects this centre line *R r*, and the versed sines of these arcs will be equal; therefore the length of that portion of the line, lying between the centre *C* and the point *g*, will be less than that portion lying between *C* and the point *h* by an amount equal to wice the versed sine of either arc, because the arc g curves inwards towards the centre C, and the rc Th curves outwards from this centre. Adding, herefore, to the former an amount equal to this ersed sine, and subtracting the same amount from the latter, makes these portions equal without affecting their sum, and this is brought about by simply dropping perpendiculars from the points D and T respectively on to the line Rr; but the lengths of those portions of the line Rr, measured from the centre C to where it is met by the perpendiculars being equal, it becomes unnecessary for us to deal with both of them; therefore, in the present case we shall only draw the perpendicular from the point D, meeting the line Rr in the point e. We will now consider how the motion of the eccentric, taken along the line CR, affects the movement of the link in the direction JL, parallel to the direction of motion of the valve-spindle. From the point g as a centre, and with a radius equal to the length of one of the eccentric rods, describe the arc aF; this will meet the line JL in the point F, and from the point h as centre, and with the same radius as before, describe the arc bU, meeting the line JL in the point U. Now Ra will be equal to Cg, and Rb to Ch, but we have already substituted the perpendiculars drawn from the points D and T on to the centre line CR in the place of the arcs, and we have shown that these perpendiculars cut off from Rr an equal amount on each side of the point *C*, so that *Ce* represents either amount; we have only, therefore, to set off on the line, *CR*, produced, these equal distances on each side of the point *R*, and to erect at the point so found perpendiculars cutting the line *JL*; but as the results on each side of the point *R* will be the same we need only set off one of these. From the point *R*, therefore, set off *Rm* equal to *Ce*, and at the point *m* erect a perpendicular cutting the line *JL* in the point *n*; then the line *Rn* represents the amount the end *F* of the link is beyond its mean central position for the position *CD* of the eccentric sheave. But to avoid all this extra trouble it is only necessary to continue the perpendicular *De* till it cuts the line *AB* in the point *X*, then *CX* will be equal to *Rn*, as can be readily proved. From the point *X* draw *XY* perpendicular to *AB*, and meeting an arc described from the centre *C* with a radius equal to *RJ* or *RL* in the point *Y*. Join *YC*. Then *YC* will represent the throw and position of an imaginary eccentric sheave, which if placed with its centre of revolution directly under the point *F* would cause that point to move *almost* exactly as it does now move under the action of the eccentric sheave *CD*, with its rod working in the mean oblique direction *CR*. We next proceed to find the imaginary eccentric sheave *CZ*, which if placed with its centre of revolution directly under the point *H* would cause that point to move *almost* exactly as it does now move under the action of the eccentric sheave *C E*, with its rod working in the mean oblique direction *C S*. Join *Y Z*, and divide this line in the same proportion as the line *A B* divides the chord, *F H*, of the link. In the present case it divides it equally; therefore the point *X*, in the line *Y Z*, corresponds to the point *t* in the *chord* of the link, and to the point *A* in the *arc* of the same, and this point *A* will travel in the line *A B* almost exactly as if it were driven by an eccentric, the throw and position of which is represented by the line *C X;* and we can ascertain the motion of any point in the arc of the link for this position of the link itself by simply finding the point in the line *Y Z*, which divides that line in the same proportion as a line drawn parallel to the centre line of the valve-spindle through the given point in the arc of the link divides the chord *F H*, but it is sufficiently accurate for all practical purposes, and with links of ordinary curvature, to divide the line *Y Z* in the same proportion as the given point divides the *arc* of the link; but as the two virtual eccentric arms, *C Y* and *C Z*, and the line, *Y Z*, joining them only refer to the middle position of the link, they having been obtained from that position, we can only use the line *Y Z* to obtain the movements of points in the link while the link is in mid-gear; and if with the link in any other position we want to find the motion of any point in the same other than the actual point in gear with the valve-spindle, and for which we shall presently explain a short method, we must obtain the virtual eccentric arms *C Y* and *C Z* and the line *Y Z* for that special position of the link. In dividing the line *Y Z* in the same proportion as the chord *F H* or the arc of the link is divided, we must take the proportion in each case from that end of the link and of the line *Y Z* which are contiguous to the same eccentric rod; thus, with "open rods" the end *Y* corresponds with the end *F*, and the end *Z* with the end *H;* but with "crossed rods" the end *Y* would correspond with the end *H*, and *Z* with *F*. We have obtained the point *Y* in the arc drawn from the centre *C* by drawing a perpendicular *X Y* from the point *X*, where the centre *A B* is intersected by the line *D X;* but there is a much simpler way of finding the point *Y*, for the angle *D C Y* is always equal to the angle *R C X;* and similarly, with regard to the point *Z*, the angle *E C Z* is always equal to the angle *S C X*, which we will proceed to prove, but as the same reasoning applies in both cases we need only deal with one of them. We will now, therefore, take the case of the point *Y*. From the point *R* set off *R p* equal to *C D*, the throw of the sheave, and at the point *p* erect a perpendicular which will meet the line *J L* in the point *J*, or at least so *very* nearly so that we may assume that it does actually meet it in that point, and draw it accordingly. Then in the triangle *R J p* the straight line *m n* has been drawn, so that it is parallel to the side *Jp*, both being perpendicular to *R p*, therefore the triangle *R J p* is equiangular to the triangle *R n m;* and as the side *R p* is to the side *J R*, so is the side *R m* to the side *R n* (Euclid, VI. 4), and in the triangles *D C e*, *Y C X*, the side *D C* is equal to *R p*, and *C Y* to *R J*, and the side *C e* is equal to the side *R m*, and *C X* to *R n*. Therefore, as *D C* is to *C Y* so is *C e* to *C X*, and the angle *D e C* is equal to the angle *Y X C*, both having been made right angles; therefore the triangle *D e C* is equiangular to the triangle *Y X C* (Euclid, VI. 7), and the angle *D C e* is equal to the angle *Y C X*: from these equal angles take away the common part *Y C e*, and the remainder *D C Y* is equal to the remainder *R C X*.

We will next take a case in which the link has been shifted into an intermediate position, such as F G (Fig. 27), where the valve-spindle, A Q, is driven by the point A in the link; we require to know what motion the valve-spindle receives.

Let *C D* and *C E*, as before, represent the throws of the eccentric sheaves and their positions relative to the position *C B* of the crank, and let *F G* represent the link and its position relative to the centre line, *A Q*, of the valve-spindle, and let *C F* and *C G* represent the lengths of the eccentric rods. Through the points *F* and *G* respectively draw the lines of travel, *H I* and *J K*, parallel to the centre line, *A Q*, of the valve-spindle. From the centre *C*, and with *B A* as radius, describe arcs intersecting these lines in

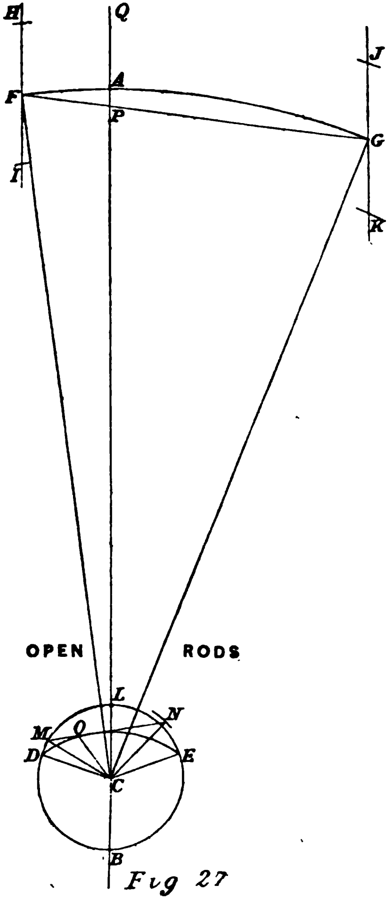


Fig 27

the points *H* and *J* respectively; similarly from the same centre, and with *LA* as radius, describe arcs intersecting the same lines in the points *I* and *K*. Then the distance *HI* will represent the travel of the point *F*, and the distance *JK* will represent the travel of the point *G*, and the points *F* and *G* respectively *almost* exactly bisect those distances. Draw *CM* equal to *FH* or *FI*, making the angle *MCD* equal to the angle *FCA*, and draw *CN* equal to *GJ* or *GK*, making the angle *NCE* equal to the angle *GCA*. Join *MN*, and divide it at the point *O*, in the same proportion as *AQ*, the centre line of the valve-spindle, divides the arc *FAG*; so that *MO* is to *ON* as *FA* to *AG*. Join *CO*. Then *CO* will represent the throw and position of an imaginary eccentric sheave, which, if connected direct to the point *A*, would cause that point to move *almost* exactly as it does under the combined action of the real eccentric sheaves *CD* and *CE*, working in the oblique directions *OF* and *OG*. And the motion of any other point in the link, while it is in the position *FG*, may be obtained by simply dividing the line *MN* in the same proportion as the given point divides the arc of the link; and by finding the throws of the two imaginary eccentric sheaves, *CM* and *CN*, for any other position of the link, the motion of any point in the same for that position may be ascertained in a similar manner, but as the point in the link of which we more particularly require to know the motion is that point in gear with the valve-spindle, we can avoid the labour of going through all the foregoing construction, for the ends of the throws of the imaginary eccentric sheaves corresponding to the various points of the link brought into gear with the valve-spindle, are found to fall in a curve which is really a portion of a parabola, but is sufficiently accurately represented by the arc *D O E* of a circle passing through the ends of the throws of the real eccentric sheaves and the end of the throw of the imaginary sheave, which refers to the motion of the centre of the link, when the link itself is in mid-gear. This method will be fully explained in Problem XVI.

We will now proceed to consider the same form of link-motion, but with "crossed rods." In the straight line *A B* (Fig. 28) take any point *C* to represent the centre of the crank-shaft carrying the eccentric sheaves, and let *C B* be the position of the crank. Draw *C D* and *C E* to represent the throws of the eccentric sheaves and their position relative to the centre-line, *C B*, of the crank. From the point *C* as centre, and with a radius equal to *C D* or *C E*, describe the circle *D E B*. From the point *D* as centre, and with a radius equal to the length of one of the eccentric rods, describe the arc *G H*, and from the point *E* as centre, and with the same radius, describe the arc *F G* intersecting the arc *G H* in the point *G*. From this point as a centre, and with a radius equal to half the length of the link, describe the arcs at *I* and *J*, and draw the straight lines *IM* and *JN*

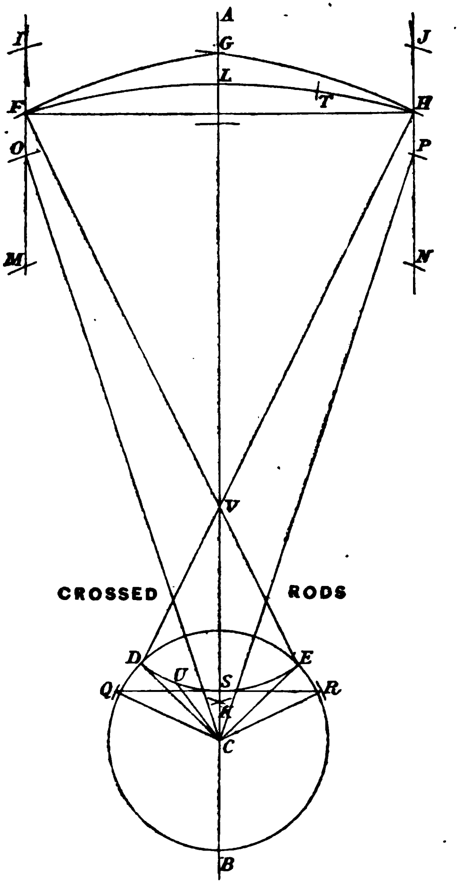


Fig. 28.

parallel to *A B*, touching the arcs drawn from the centre *G*, and cutting the arcs *F G* and *G H* in the points *F* and *H* respectively. Join *F H*. From the points *F* and *H* as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at *K*, and from this point as centre, and with the same radius, describe the arc, *F L H*, of the link. From the centre *C* set off upon *I M* and *J N* respectively the points *I*, *M*, *J* and *N* representing the extent of the travel of the ends *F* and *H* of the link, in the manner already described. And similarly, from the same centre, and with a radius equal to the length of the eccentric rods, describe the arcs at *O* and *P*, bisecting the lines *I M* and *J N* in these points respectively. Join *C O* and *C P*, then draw the eccentric rods *F E* and *D H*, which will be seen to cross each other at the point *V*, while the crank is in the position *C B*, hence the combination is termed a link-motion with "crossed rods." Draw *C Q* equal to *P J* or *P N*, making the angle *D C Q* equal to the angle *P C A*, and draw *C R* equal to *O I* or *O M*, making the angle *E C R* equal to the angle *O C A*; the reason for these angles being made equal has been already fully explained (page 114). Join *Q R*, and divide it in the same proportion as the centre line, *A B*, of the valve-spindle divides *F L H*, the arc of the link; in the present case, this arc is divided by *A B* into two equal parts, therefore we divide *Q R* in the same manner in the point *S*, then the line *C S* will represent the throw and position of the single virtual eccentric arm which would drive the centre point, *L*, of the link *almost* exactly in the same manner as it is really driven by the combined action of the eccentric sheaves *C D* and *C E*, with the link occupying its middle position with regard to the valve-spindle; and we can, as before, ascertain the motion of any other point in the link, for this position of the link itself by simply finding the point in the line *Q R* that divides it in the same proportion as the given point divides the arc of the link, but as the point in the link of which we more particularly require to know the motion is that in gear with the valve-spindle, we can in this case, as well as in the previous one with open rods, avoid the labour of going through the full construction for every position of the link, as it is found that the ends of all the single virtual eccentric arms are contained in a curve which, as before, *almost* exactly coincides with an arc of a circle *D S E*, passing through the ends of the arms of the real eccentric sheaves and the end of the throw of the imaginary or single virtual eccentric sheave, which refers to the motion of the centre of the link, when the link itself is in mid-gear. Through these points *D*, *S* and *E* describe this arc, and the motion of any point *T* in the arc of the link will be ascertained by finding a point *U* in the curve *D S E* which will divide it in the same proportion as the arc of the link is divided by the point *T*, the proportion being taken in each case from that end of the link and that end of the arc *D S E*, which are contiguous to the same eccentric rod.

In the foregoing we have intimated from time to time that the construction indicated does not in every detail yield results so *absolutely* accurate as to be capable of direct mathematical proof, but nevertheless the construction *does* give results so *very* nearly approaching to *absolute* accuracy, that the deviation therefrom cannot be appreciated in practice, and it must be borne in mind that in our diagram any such deviations are much exaggerated, for in order to make the rest of the figure of sufficiently large dimensions and yet to get the whole within the compass of a page, we have been obliged to draw the eccentric rods *very* much shorter in proportion than is usual in practice, hence there appears to be so great a distance between the points *X* and *I* (Fig. 26) and the points *F* and *n*: for were the eccentric rods of indefinite length, these points respectively would actually coincide, but even were the rods drawn of a length bearing a *fair proportion* to the length of the link and the travel of the valve, then these points would *to all intents and purposes* coincide, and the distance of the point *F* from its *real* centre of travel would practically be the same as its distance from its *mean* centre.

The throws of the two imaginary eccentric sheaves which refer to the extreme ends of the link are termed he *virtual forward and backward eccentric arms,* and he throw of the imaginary eccentric sheave which refers to the motion of an intermediate point in the ink, is termed *the single virtual eccentric arm;* and it will be noticed that the curve containing the ends of all the single virtual eccentric arms is always *convex* towards the link where "open rods" are used, and *concave* towards the link when "crossed rods" are applied; hence, as will be seen from the following problems, when *open* rod combinations are used, the lead of the valve *increases* as the link is brought nearer to mid-gear with the valve-spindle, but with *crossed* rod combinations the lead *diminishes* as the link is brought nearer to mid-gear, and in both cases the shorter the rods are in proportion to the length of the link the greater is the alteration in the amount of lead, so that where it is desired that the lead shall undergo the least possible change in using different positions of the link, it is necessary to use the longest rods that circumstances will admit of, and as short a link as the travel of the valve will allow. With regard to the method of shifting the link, this is effected by means of a short rod $l A$ (Fig. 26), one end of which is attached to the link itself at the point A, bisecting the arc, which in practice is struck through the middle of the slot; sometimes, however, another point is taken; in any case the other end of this rod is attached to a lever or sliding-piece at a point opposite to the central position of the point of attachment to the link, and the motion of this point must be at right angles, or approximately at right angles, to the direction of motion of the valve-spindle.

PROBLEM XVI.

iven the throws of the forward and backward eccentric sheaves, and their positions relative to the centre line of the crank, also the length of the link and of the eccentric rods. It is required to know what motion the valve-spindle will receive from any given point in the link, if the link itself is shifted so as to bring that point into gear with the valve-spindle.

Let the straight line *A B* (Figs. 29 and 30) represent the length of the link, and we will suppose the link to be in middle gear. From the points *A* and *B* respectively as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at *C*, and from the point *C* as centre, and with the same radius, describe the arc of the link *A K B*. Bisect the chord *A B* in the point *F*. Through the points *F* and *C* draw the centre line *F C L*, and from the point *C* set off *C D* and *C E* to represent the throws of the eccentric sheaves and their positions relative to the real position, *C L*, of the crank, and from the point *C* as centre, with radius *C D* or *C E*. describe the circle *D E L*. Upon *D C* as a diameter describe the valve-circle *D G C*, and join *A C*, cutting

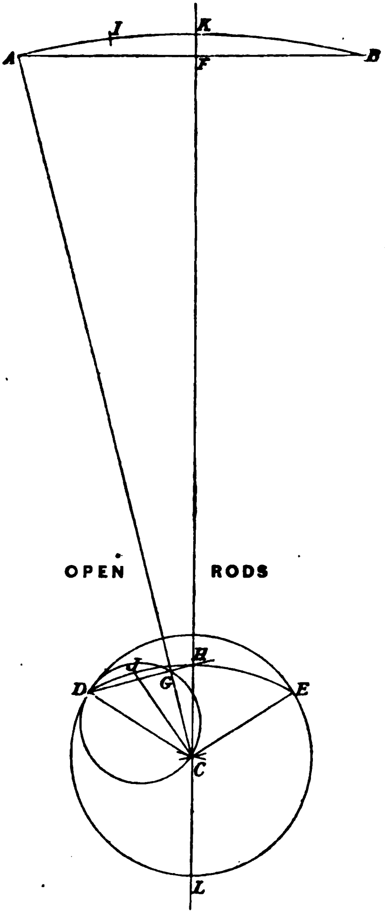


Fig. 29

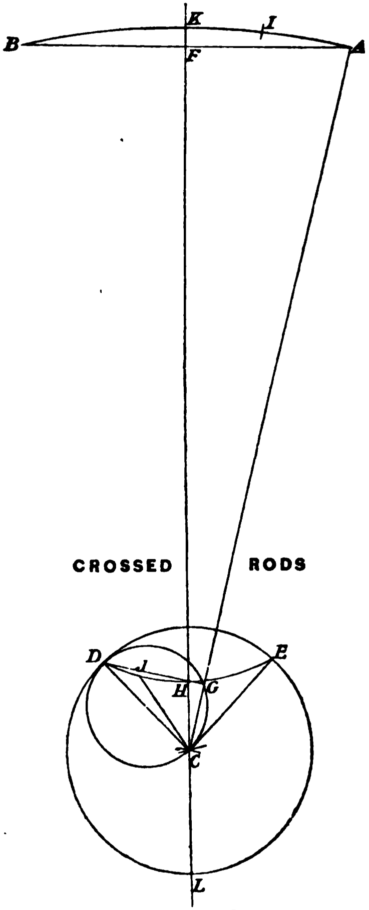


Fig. 30

this valve-circle in the point *G*. Through the points *D* and *G*, draw a straight line, cutting the centre line *F C* in the point *H*. Through the three points *D*, *H* and *E* describe an arc of a circle; then, if we require to know how the valve-spindle would be moved by any point in the link which we might bring into gear with it by shifting the link, we have only to find that point in the arc, *D H E*, which divides it in the same proportion as the given point divides the arc of the link, the proportion being reckoned in each case from the ends of the link and of the arc *D H E*, which are contiguous to the same eccentric rod. Thus we have only to divide the arc *D H E* in the point *J*, so that *D J* is to *J E* as *A I* is to *I B*, and to join *C J*, then *C J* will represent the throw and position of the single virtual eccentric sheave, which, if connected direct to the point *K*, would move it *almost* exactly as the point *I* in the link would cause it to move if the link were shifted into that position.

PROBLEM XVII.

The length of the link and of the eccentric rods being known, and the link being in full backward or forward gear, and the lead, the point of cut-off, and either the amount the port is to be open for a given position of the crank, or the utmost amount that it is to be open for any position whatever of the same being given, it is required to find the throw and position of the forward and backward eccentric sheaves, and the lap of the valve: also given the various positions of the crank at which the cut-off of the steam shall take place, it is required to find those positions of the link which will effect the same.

This problem is more especially applicable where such a form of link is used as will allow of the eccentric rod being thrown into absolutely full gear with the valve-spindle. Let the straight line AB (Figs. 31 and 32) represent the length of the link. From the points A and B respectively as centres, and with a radius equal to the length of one of the eccentric rods, describe arcs intersecting at C, with this point as centre, and with the same radius describe the arc of the link ADB; bisect AB in E, and through the points E and C, draw the centre line $D\,E\,C$. *Then by either Problem III. or Problem IV., as the case may be, find the throw of the eccentric sheaves, and their position relative to the real position of the crank, also the lap of the valve: having done this, transfer the results to the link diagrams (Figs. 31 and 32), drawing $C\,F$ and $C\,G$ to represent these throws of the sheaves and their position relative to the real position, $C\,Z$, of the crank, and from the centre C describe the lap-circle $V\,P\,N$, and from the same centre, and with a radius equal to $C\,F$ or $C\,G$, de-

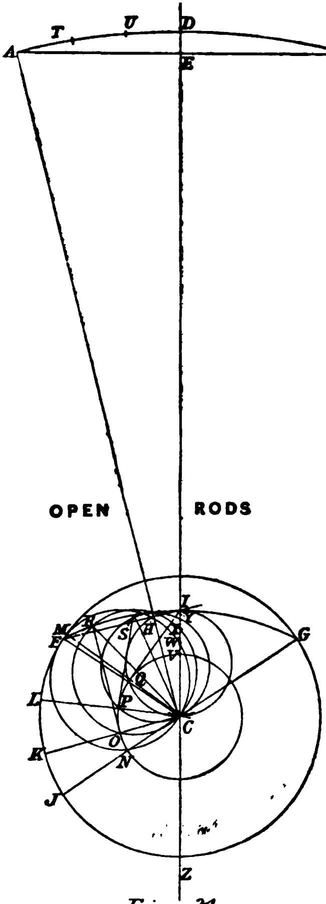


Fig 31

ribe the circle *K F G*, and draw *J C* to represent he direction of the rank at which the team is cut off when he link is working n full gear, and draw *K C*, *L C*, and *M C* o represent the various positions of the crank at which it is required that the steam *may* be cut off by moving the link. We have now to find those positions of the link which will effect the same. Join *A C*, and upon *F C* as a diameter describe the valve-circle *F H C* cutting *A C* in the point *H*. Through *F* and *H* draw a straight line, cutting the centre line *D Z* in the point *I*. Through the points *F*, *I*, and *G* describe the arc of a circle. At the

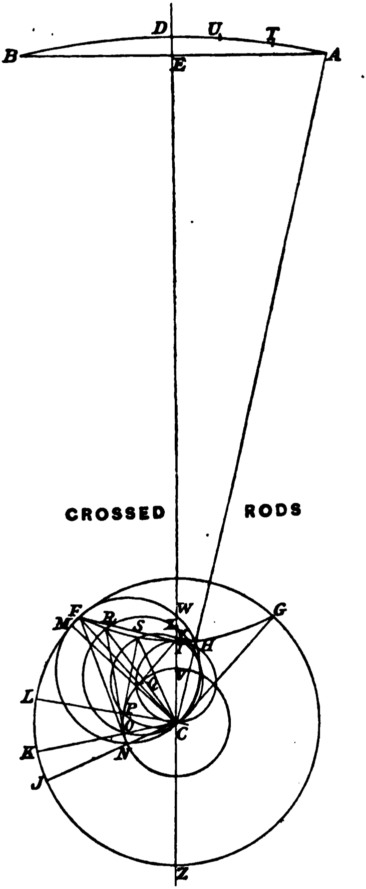


Fig. 32.

points *O*, *P*, and *Q*, at which the lap-circle cuts the lines *K C*, *L C*, and *M C* respectively, erect perpendiculars cutting the arc *F I G* in the points *R*, *S*, and *I* respectively; then divide the arc *A D B* of the link in the same proportion as the points *R*, *S*, and *I* divide the arc *F I G*, and let the point *T* correspond to the point *R*, and the point *U* to the point *S*, and the point *I*, which bisects the arc *F I G*, will correspond to the point *D*, bisecting the arc of the link. Join *C R* and *C S*, for the points *I* and *C* are already joined by a portion of the centre line *D Z*. Then the lines *C R*, *C S*, and *C I* will represent the single virtual eccentric arms referring to the points *T*, *U*, and *D* of the link respectively, that is, if the link be moved so that any one of these points be brought into gear with the valve-spindle, then the valve-spindle will be moved by any such point *almost* exactly as though it were driven direct by an eccentric whose throw and position is represented by this line. Upon *C R*, *C S*, and *C I* respectively as diameters, describe the valve-circles *C O R*, *C P S*, and *C Q I*; these will pass through the points *O*, *P*, and *Q* respectively, where the lines *K C*, *L C*, and *M C* intersect the lap-circle *V Q N*; hence the steam will be cut off from the cylinder when the crank reaches that position in which its centre line passes through the point of intersection of the lap-circle and that valve-circle which corresponds to the position in which the link then is. The next point we have to consider is the amount of lead the valve has for each of the various positions of the link. Taking first the link in full gear so that the point *A* in the link becomes concentric with the centre of the end of the eccentric rod, and the valve-spindle is driven by the real eccentric arm *C F*, as though its eccentric rod were connected direct on to it without any link intervening, the valve will have a lead equal to *V W*, which is equal to the given lead; for, by Problem III. or IV., we made *C F* the throw and position of the eccentric sheave which would give the lead, the opening of the port, and the point of cut-off required. We next take the point *T* in the link, and find upon referring to the corresponding valve-circle, that the valve will have a lead equal to *V X* when the link is shifted, so as to bring this point into gear with the valve-spindle; and, similarly, *V Y* will be the lead when the point *U* is brought into gear. When we come to the centre of the link we find that if the link is placed in mid-gear, as shown in the diagram (Figs. 31 and 32), the valve will have a lead equal to *V I*, but in this position of the link the valve only opens the amount *V I* altogether, and it travels altogether from its central position an amount equal to *C I;* hence, when the link is in mid-gear, the travel of the valve is equal to the lap plus the lead, and the amount the port opens is only equal to the lead. From the foregoing it will be seen that, as we have already stated, when open rods are used, the lead of the valve increases as the link is brought nearer to middle gear, but with crossed-rods the reverse is the case. In practice, however, this increase is *very* considerably less than that indicated by our diagram: for we have, as previously stated, been compelled to make our eccentric rods so short as to be altogether out of proportion to the length of the link, in order to get the figure within the size of the page.

PROBLEM XVIII.

The length of the link and of the eccentric rods being known, and the link being in such a position that a given intermediate point in the same drives the valve-spindle; also the lead, the point of cut-off, and either the amount the port is to be opened at a certain position of the crank, or the utmost amount it is to be opened by this point in the link for any position whatever of the crank being given; it is required to find the throw and position of the forward and backward eccentric sheaves and the lap of the valve. Also given the various positions of the crank at which the cut-off of the steam shall take place, it is required to find those points in the link which will effect the same.

This problem is especially applicable in cases where a form of link is used which will not admit of the eccentric being thrown into absolutely full gear with the valve-spindle; for instance, if we take that form of link in which the eccentric rods are attached to each end of the link beyond the ends of the slot, in such cases the theoretical link is measured from pinhole to pinhole, where the eccentric rods are fastened on, and each extreme position of the slider becomes only an intermediate position in our link diagram.

Let the straight line *A B* (Figs. 33 and 34) represent the length of the link measured from centre to centre of the pin-holes where the eccentric rods are attached, and it matters not whether the link can be shifted so far as to bring these points into gear with the valve-spindle, or whether the points *G* and *Z* are the extreme points that can be so used, as in either case it is these particular points, *G* and *Z*, with which we have to deal, and we have to cause either of them to move the valve in accordance with the

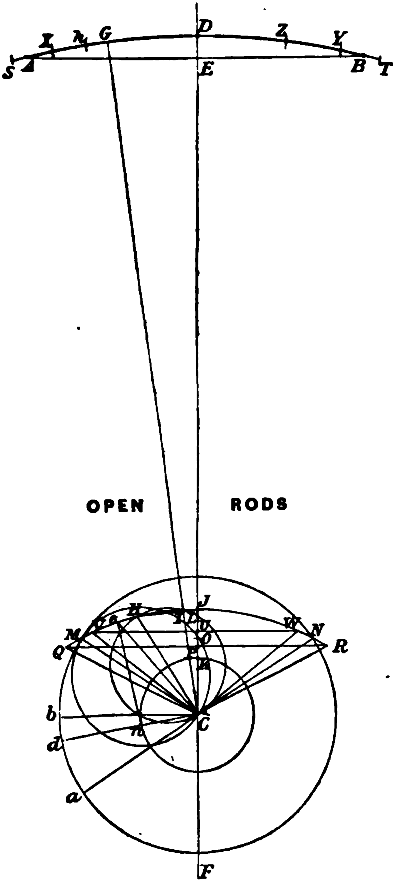


Fig. 33.

given requirements, when they are brought into direct gear with the valve-spindle. From the points *A* and *B* as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at *C*, and these rods are taken here very much shorter in proportion than they would be in practice, in order to get the diagram within the page. From this point *C* as a centre, and with the same radius, describe the arc, *A D B*, of the link. Bisect *A B* in *E*, and through this and the point *C* draw the centre line *D F*. *By Problem III. or Problem IV., as the

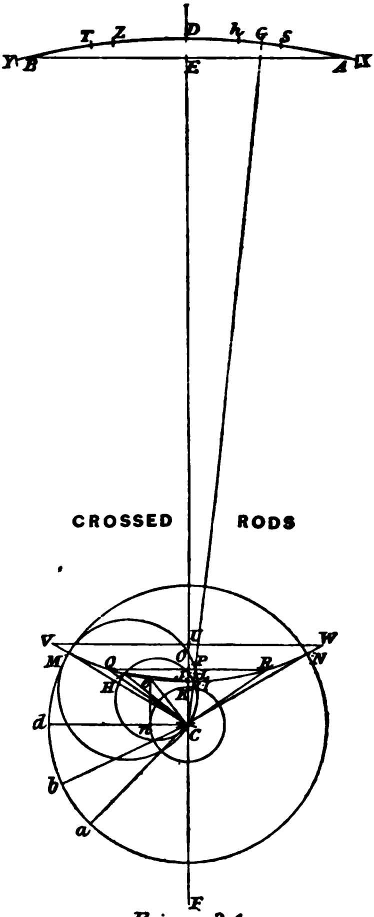


Fig. 34.

case may be, find the throw of an eccentric sheave and its position relative to the real position, *CF*, of the crank, which, if connected by an eccentric rod direct on to the valve-spindle, would produce the required results. These results are taken differently, though under the same lettering, in the two diagrams (Figs. 33 and 34), one referring to open and the other to crossed rods. However, having obtained these particulars, we transfer them to our two link diagrams respectively, drawing *CH* to represent the throw and position of this eccentric sheave, and describing the lap-circle about the centre *C*. Let *G* be the point in the link which is to produce the required motion of the valve. Join *GC*. Upon *HC* as a diameter describe the valve-circle *HLC*, cutting *CG* in the point *I*. Through *H* and *I* draw a line cutting the centre line, *CD*, in the point *J*. With its centre somewhere in the line *DF*, describe an arc of a circle passing through the points *H* and *J*, and set off *HM* to bear the same proportion to *HJ* as *GA* does to *GD*. Join *CM*. From the point *C* as centre, and with radius *CM*, describe a circle. Draw the radius *CN*, making the angle *JCN* equal to the angle *JCM*. Then *CM* and *CN* will represent the throws and positions of the real eccentric sheaves, whose rods being attached to the points *A* and *B*, the extreme ends of the link, the link itself being placed in such a position that the point *G* drives the valve-spindle, will cause the valve to be moved *almost* exactly as it would be if driven direct by an eccentric whose throw and position are represented by *CH*. Upon *MC* as diameter describe the valve-circle *MOC*. If we now examine the diagram, we find that *KO* represents the lead of the valve when the point *A*, at the extreme end of the link, is brought into direct gear with the valve-spindle, and *Ca* represents the position of the crank when the steam is cut off. And further, when the point *G* in the link drives the valve-spindle, then the valve has a lead, *KL*, equal to the given amount of lead, and cuts off the steam when the crank reaches the position *Cb*, representing the given position at which the cut-off was to take place, because we made *CH* to represent the throw and position of an eccentric sheave, which would effect a distribution of the steam in accordance with the given particulars. We will now assume that it is required to find a point in the link which, if brought into gear with the valve-spindle, would cause the cut-off to take place when the crank reaches any position, such as *Cd*. At the point *n*, where *Cd* cuts the lap-circle, erect a perpendicular cutting the arc *MJN* in the point *e*. Join *Ce*, and divide the arc of the link in the same proportion as the point *e* divides the arc *MJN*, the proportion being taken in each case from the ends of the link, and of the arc *DSE*, which are contiguous to the same eccentric rod. Let *h* represent this point in the link. In a similar manner any other point in the link may be found which, if brought into gear with the valve-spindle, will cause the cut-off to take place at given positions of the crank, but no earlier cut-off can be effected than that produced by the central position of the link, that is by the link in mid-gear. We have already pointed out that, when the point *A* in the link drives the valve-spindle, the valve has a lead equal to *K O*, because the valve-spindle is then driven by the eccentric in full gear, and therefore the real eccentric arm becomes the single virtual eccentric arm for that position of the link. Now, supposing it is required that when the link is in full gear, so that the end where the eccentric rod is attached drives the valve-spindle, the valve should have a greater or less lead than *K O*, we proceed as follows:—Set off from the point *K* the required lead on the centre line, and let *K P* or *K U* represent this lead, which distances we have taken, the one greater and the other less than *K O*. Through the points *P* or *U* draw a straight line at right angles to the centre line *D F*, cutting the arc, *M J N*, produced in the points *Q*, *R*, *V* and *W*. Join these several points with the centre *C*. Then if a lead equal to *K U* is required, the points *V* and *W* will represent the ends of the arc, and *C V* and *C W* will represent the throws and positions of the eccentric sheaves; but, in order to maintain the necessary proportion, we must alter the length of the link itself in the same ratio as we have altered the length of the arc *M J N*. Let *X D Y* represent the arc of the link of the altered length, then the point *G* will still divide the arc, *X D Y*, of the link in the same proportion as the point *H* divides the arc *V J W*. Similarly, if we require a lead equal to *K P*, the points *Q* and *R* will represent the ends of the arc, and *C Q* and *C R* will represent the throws and positions of the eccentric sheaves; but again, in order to maintain the necessary proportion, we must alter the length of the link itself in the same ratio as we have altered the length of the arc *M J N*. Let *S D T* represent the arc of the link of the altered length, then the point *G* will, as before, still divide the arc *S D T* of the link in the same proportion as the point *H* divides the arc *Q J R*. From the foregoing it will be seen that it matters not whether the link be driven by an eccentric arm, *C M*, connected by its rod to the point *A* of the link, or whether it be driven by an eccentric arm *C Q* or *C V*, with its rod attached to the points *S* or *X* in the link.

GOOCH'S LINK-MOTION.

In this combination (Figs. 35 and 36) the link is also curved, but with its *concave* side towards the valve-spindle. The link itself, however, is not shifted to vary the position of the slider, as in Stephenson's arrangement, the valve-spindle being driven by the link through an intermediate connecting-rod *O W*, termed the radius rod, attached to the slider, and the link itself is curved to a radius equal to the length of this rod, and is maintained in its central position by being attached to one end, *Y*, of a rod *Y Z*, the other end, *Z*, of which swings on a stud fixed opposite to the central position of the point of attachment to the link; which point of attachment should fall in and bisect the arc of the link, this arc being struck through the centre of the slot; another position, however, is sometimes chosen for this connection. The radius rod, *O W*, is attached at any point *b* in the same (generally somewhere about the middle of its length) to one end of a rod *b a*, the other end, *a*, of which is connected to a lever or sliding-piece at the point *a*, opposite to the central position of *b*, the point of attachment to the connecting-rod, the mean motion of the point *a* in the lever or sliding-piece being at right angles to

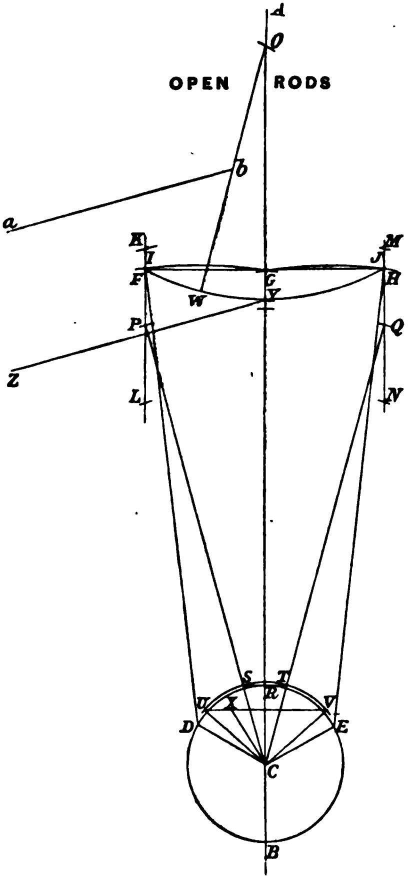


Fig. 35.

the direction of motion of the valve-spindle *A O*.

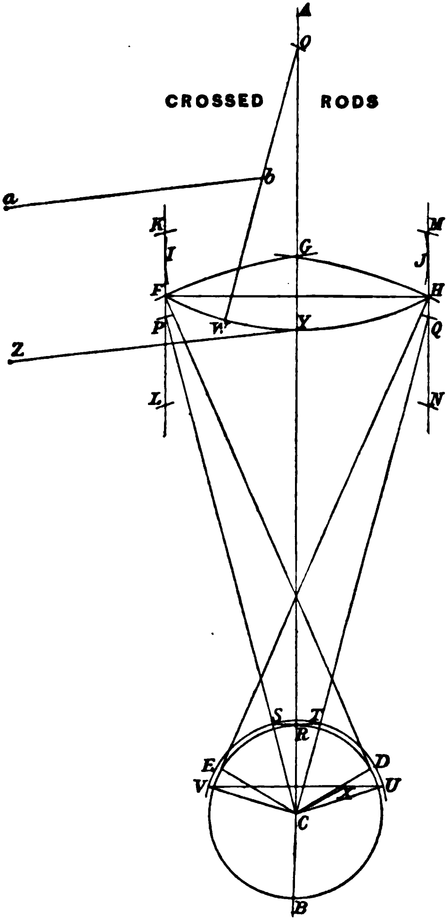


Fig. 36.

Now as the link itself is not shifted, but always occupies a position such that its centre travels backwards and forwards along *A C*, the centre-line of the valve-spindle (the only deviation from this being due to the small arc described by the rod *Y Z* carrying the link), it is only necessary to find the virtual forward and backward eccentric arms *C V* and *C U* once, for all positions of the slider, in the same manner as we did in the case of Stephenson's link-motion, and to draw a straight line joining the ends, *V* and *U*, of these, and divide this line, *V U*, in the same proportion as the slider divides the arc, *F Y H*, of the link: then the line drawn from this point of division to the centre of revolution of the eccentric sheaves will represent the single virtual eccentric arm, and its position relative to the crank; and, as in this link-motion, the line containing the ends of all the single virtual eccentric arms is straight instead of curved, the lead remains the same for all positions of the slider. The construction is as follows:—In the straight line *A B* (Figs. 35 and 36) take any point *C*, and draw *C D* and *C E* to represent the throws and positions of the eccentric sheaves, and from the same point as centre, and with radius *C D* or *C E*, describe the circle *D E B*. From the points *D* and *E* as centres, and with a radius equal to the length of the eccentric rods, describe the arcs *F G* and *G H* intersecting at the point *G* (which point *G* does not necessarily fall in the line *F H*, Fig. 35). From this point as a centre, and with a radius equal to half the length of the link, describe the arcs at *I* and *J*, and draw the lines *K L* and *M N* parallel to *A B*, touching these arcs, and cutting the arcs *F G* and *G H* at the points *F* and *H* respectively. Join *F H*. From the point *F* as a centre, and with a radius equal to the length of the radius rod, describe an arc cutting *A B* in the point *O*, and from this point as a centre, and with the same radius, describe the arc of the link. Join *D F* and *E H*: these lines will represent the eccentric rods. From the centre *C* set off upon *K L* and *M N* respectively the points *K*, *L*, *M* and *N*, representing the extent of the travel of the ends of the link; the method of doing this has been already described (p. 109). Similarly, find the points *P* and *Q* bisecting *K L* and *M N*. Join *C P* and *C Q*, and through the point *R*, where the centre line, *A B*, is cut by the circle *D E B*, draw *S T* at right angles to *A B*, cutting the lines *C P* and *C Q* in the points *S* and *T* respectively. From the centre *C*, and with a radius *C S* or *C T*, describe the arc *U T V*, and draw the radii *C V* and *C U*, making the angles *U C D* and *V C E* equal to the angles *S C R* and *T C R* respectively in Fig. 35 and alternately in Fig. 36; in the present case, however, they are equal. Then *C V* and *C U* will represent the virtual forward and backward eccentric arms. Join *V U*. We will now assume that any point *W* in the link drives the valve-spindle. Join *W O*, then this line will represent the radius-rod, and in order to ascertain how the valve-spindle is driven by the point *W* in the link we have only to divide the line *U V* in the same proportion as the point *W* divides the arc *F Y H* of the link, the proportion being taken in each case from that end of the link and of the line *U V*, which are contiguous to the same eccentric rod.

In the following problems, as in those relating to Stephenson's link-motion, the results, though not *absolutely* correct in every detail, so as to be capable of direct mathematical proof, do nevertheless under ordinary conditions so *very* nearly approximate to perfect accuracy that any deviation therefrom is inappreciable in practice; if *very* short rods, however, are used, it may in some *extreme* cases be desirable to discard the use of valve-circles, and draw instead the arcs described by the eccentric rods. In dividing the line *U V* in the same proportion as the given point divides the link, we have considered the *arc* of the link; this, as we have already explained, being under usual conditions sufficiently accurate for all practical purposes, but in the case of a link being used which is unusually curved, the points in the arc may be projected on to the chord by lines drawn through these points parallel to the centre line of the valve-spindle, and the line *U V* should then be divided in the same proportion as the given points projected divide the chord.

PROBLEM XIX.

Given the throws of the forward and backward eccentric sheaves and their positions relative to the centre line of the crank; also the length of the link and of the eccentric rods and radius rod. It is required to ascertain what motion the valve-spindle will receive from any given point in the link, if the end of the radius rod with the slider is shifted to that point; also given any position of the crank at which the cut-off of the steam shall take place, it is required to find that position of the slider in the link which will effect the same.

Let the straight line AB (Figs. 37 and 38) represent the length of the link. From the points A and B as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at C, and from the same points as centres, and with a radius equal to the length of the radius rod, describe arcs intersecting at D; through the points D and C draw the centre line DCE. Join CA. Draw CF and CG to represent the throws of the eccentric sheaves and their position relative to the real position, CE, of the crank. From the point C as centre, and with radius equal to CF

or $C\,G$, describe the circle $F\,G\,E$ cutting the centre

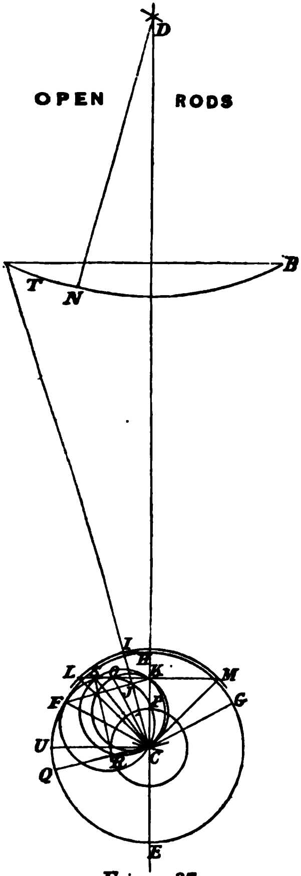


Fig. 37.

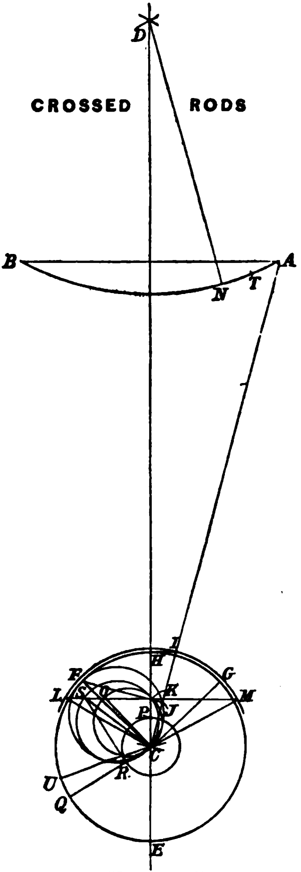


Fig. 38

line, *C D*, in the point *H;* through this point draw a straight line parallel to *A B*, cutting the line *C A* in the point *I*. From the centre *C*, and with *C I* as radius, describe the arc *L I M*. Upon *F C* as a diameter describe the valve-circle cutting the line *A C* in the point *J*. Through the points *F* and *J* draw a line cutting the centre line, *C D*, in the point *K*. Through this point draw a straight line parallel to *A B*, meeting the arc *L I M* in the points *L* and *M*. Join *L C* and *M C;* these will be the virtual forward and backward eccentric arms, and represent the movements of the extreme ends of the link; the movement of any intermediate point in the link may be found by dividing the line *L M* in the same proportion as the given point divides the arc of the link; the proportion being taken in each case from that end of the link and of the line *L M*, which are contiguous to the same eccentric rod, and the point in the line *L M* being so found it is only necessary to draw a line between it and the centre *C*, and this line will represent the throw and position of the single virtual eccentric arm, which, neglecting the theoretical error due to the angular motion of the rod already explained to be practically inappreciable, would, if connected by an eccentric rod direct on to the given point in the link, cause that point to move almost exactly as it is moved by the combined action of the real eccentrics and their oblique rods. For example, we will suppose that the slider is brought into the position DN, we then find the point O in the line LM, which divides that line in the same proportion, as the point N divides the link, so that as BN is to NA so is MO to OL. Join OC, this will represent the single virtual eccentric arm, which, if connected by a rod direct to the valve-spindle, neglecting any error due to the angular motion of the rod, would drive it almost exactly as it is really driven by the combined action of the eccentric sheaves, CF and CG, with their oblique rods. Let CQ be one of the positions of the crank at which it is required that the steam shall be cut off from the cylinder. At the point R, where CQ intersects the lap-circle, erect a perpendicular, cutting the line LM in the point S. Divide the link AB in the same proportion as the point S divides the line LM, and let the point of such division in the link be T. Join SC, this will represent the position and throw of the single virtual eccentric arm which, if connected direct on to the valve-spindle, would drive it almost exactly as it is really driven by the point T in the link under the combined motion of the eccentrics CF and CG. Upon SC as a diameter describe the valve-circle SKC, intersecting the lap-circle in the same point R, where it is already intersected by the centre line, CQ, of the crank. It will now be quite evident that when the slider is at the point T in the link, the port is closed, and the steam cut off when the crank reaches the position *C Q* as was required.

If we describe the valve-circle upon the virtual eccentric arm *O C*, we shall find that when the slider occupies the corresponding position at *N* in the link the port is closed, and the steam cut off when the crank reaches the position *C U*.

PROBLEM XX.

The length of the link and of the radius and eccentric rods being known, and the valve-spindle brought into gear with the end or any other point in the link, and the lead, the point of cut-off and either the amount the port is to be opened at a certain position of the crank, or the utmost amount that it is to be opened by this point in the link for any position whatever of the crank being given, it is required to find the throw and position of the forward and backward eccentric sheaves and the lap of the valve. Also any position of the crank at which the cut-off of the steam shall take place being given, it is required to find that position of the slider in the link which will effect the same.

Let the straight line AB (Figs. 39 and 40) represent the length of the link. From the points A and B as centres, and with radii equal to the length of the eccentric rods, describe arcs intersecting at C, and from the same points as centres, and with a radius equal to the length of the radius rod, describe arcs intersecting at D. Through the points D and C draw the centre line DCP, which will bisect the arc of the link in the point E. Join AC. Let F be the point in the link which is to drive the valve-spindle by means of the rod *D F*, and find by

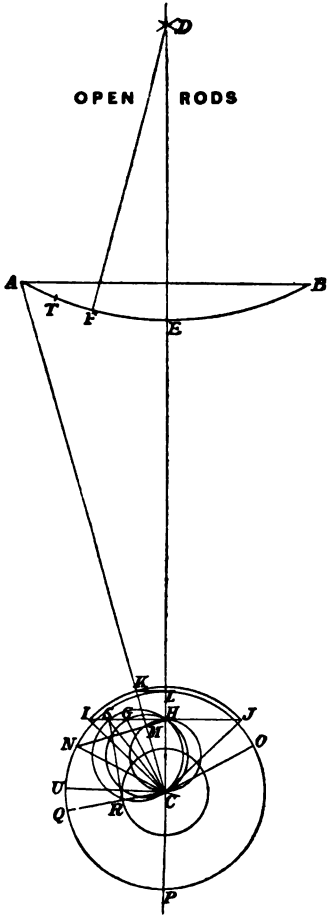


Fig. 39.

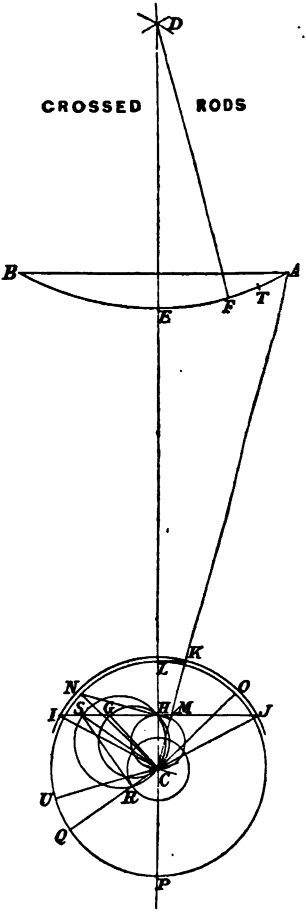


Fig. 40.

Problem III. or Problem IV., as the case may be, the throw of an eccentric sheave, and its position relative to the real position, *C P*, of the crank, which, if connected by an eccentric rod direct on to the valve-spindle, would produce the required results. Find also the lap of the valve, and transfer these particulars to the two link diagrams, drawing *C G* to represent the throw and position of this eccentric sheave, and describing the lap-circle about the centre *C*. Through the point *G* draw *I J* parallel to *A B*, making *H I* equal to *H J*, each bearing the same proportion to *H G* as *E A* bears to *E F*. Join *I C* and *J C;* these will be equal to each other. And from the centre *C*, and with radius *C I* or *C J*, describe the arc *I K J*, cutting the line *C A* in the point *K*. Through this point draw *K L* parallel to *A B*, and meeting the centre line at the point *L*. From the centre *C*, and with *C L* as radius, describe the circle *N O P*, then the real eccentric arms will be radii of this circle. Upon *C H*, as a diameter, describe a circle cutting *C A* in the point *M*. Through *H* and *M* draw a line cutting the circle *N O P* in the point *N*. Set off *L O* equal to *L N*, and join *N C* and *O C*. These will represent the real forward and backward eccentric arms, that is, the throws of the eccentric sheaves and their positions relative to the real position, *C P*, of the crank; so that if these are connected by eccentric rods to the ends *A* and *B* respectively of the link, they will by their combined action cause the point *F* to move *almost* exactly as though it were connected direct to the eccentric sheave, whose throw and position are represented by the line *C G*. Let *C Q* be the assumed position of the crank, representing one of the given positions at which it is required that the steam shall be cut off from the cylinder. At the point *R*, where *C Q* intersects the lap-circle, erect a perpendicular cutting the line *I J* in the point *S*. Divide the link *A E B* in the same proportion as the point *S* divides the line *I J*, and let this point of division in the link be *T*. Join *S C;* this will represent the position and throw of the single virtual eccentric arm, which, if connected direct on to the valve-spindle, neglecting any error due to the angular motion of the rod, would drive it *almost* exactly as it really would be driven by the point *T* in the link under the combined motion of the eccentrics *C N* and *C O*. Upon *S C* as a diameter describe the valve-circle *S H C*, intersecting the lap-circle in the same point *R*, as that in which it is already intersected by the centre line, *C Q*, of the crank. It will now be quite evident that, when the slider is at the point *T* in the link, the port is just closed, and the steam cut off when the crank reaches the position *C Q*, as was required. If we describe the valve-circle upon the virtual eccentric arm *G C*, we shall find that, when the slider occupies the corresponding position at *F* in the link, the port is closed and the steam cut off when the crank reaches the position *C U*.

ALLAN'S LINK-MOTION.

We now come to the third form of link-motion, a combination of the two previous ones. For while these had the links curved, the concave side in the one case being turned towards the shaft, and in the other towards the valve-spindle, this third, in which a straight link is adopted, forms, as it were, a mean between the other two. In the first arrangement the link itself was moved relative to the valve-spindle; but in the second the link remained still, while a rod, termed the "radius rod," and connected with the valve-spindle, was moved relative to the link. In the third arrangement, however, both the shifting link and a radius rod are employed and moved in opposite directions by means of a rocking shaft; and as it is of the first importance that the two opposite movements thus imparted to the link and rod respectively should bear a definite ratio to each other, we shall presently describe the method of determining this. In Allan's link-motion, as in Stephenson's, the lead increases as the link is brought nearer mid-gear when open rods are used, and decreases with crossed rods; this variation in lead, however, is, in both arrangements of rods, less than that which takes place with Stephenson's combination, but we have, as in Gooch's link-motion, to provide for two sets of rods moving radially about fixed or *virtually* fixed points. Hence, unless the engine is constructed with sufficient distance between the steam-chest and crank-shaft, we get our eccentric rods and radius-rod unusually short; and in very extreme cases of this kind, instead of describing valve-circles upon the several single virtual eccentric arms, we may project the ends of these on to the centre line by means of arcs described with a radius equal to the length of the eccentric rods, from a point in the centre line which represents the end of the valve-spindle at that moment; but such are rarely, if ever, met with in practice.

PROBLEM XXI.

Given the throws of the forward and backward eccentric sheaves and their positions relative to the centre line of the crank, also the length of the link and of the radius and eccentric rods. It is required to know what motion the valve-spindle will receive from any given point in the link if the slider is brought into gear with that point. Also, given the various positions of the crank at which the cut-off of the steam is to take place, it is required to find those positions of the slider in the link which will effect the same.

Let the straight line *A B* (Figs. 41 and 42) represent the length of the link. From the points *A* and *B* as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at *C*. From this point as centre, and with the same radius, describe the arc *A E B*. Bisect *A B* in *D*, and through the points *C* and *D* draw the centre line *F D C*. Set off *D F* equal to the length of the radius rod, and from the point *F* as centre, and with radius *D F* describe the arc *G D H*, cutting the arc *A E B* in the points *G* and *H*. Join *A C* and *G C*. Draw *C I* and *C J* to represent the throws of the eccentric sheaves and their position relative to the real position, *C U*, of the crank. From the point *C* as centre, and with a radius equal to *CI* or *CJ*, describe the circle *IJ U*. Upon *C I* as a diameter describe the valve-circle *IK C*, cutting *A C* and *G C* in the points *K* and *M* respectively. From the point *I*, and through the points *K* and *M*, draw straight lines cutting the centre line *D U* in the points *L* and *N* respectively. From the point *O*, where the circle *IJ U* cuts the centre line *D U*, draw *O P* parallel to *AB*, cutting *G C* in the point *P*. From the point *C* as a centre, and with radius *C P*, describe the arc *Q P R*. Through the

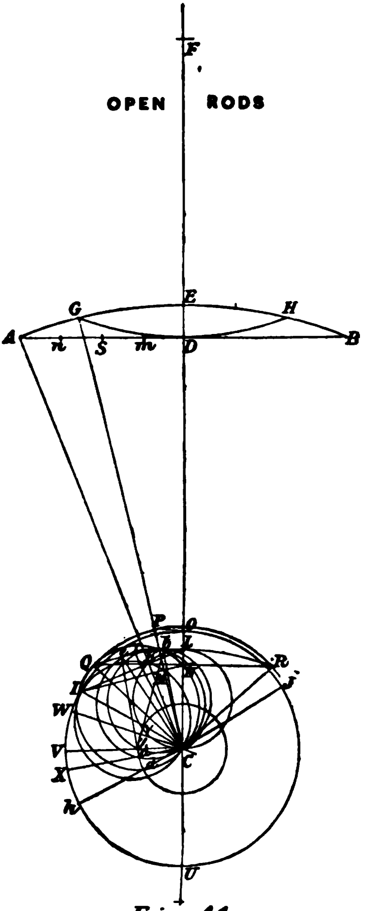


Fig. 41

point *N* draw a straight line parallel to *A B*, meeting the arc *Q P R* at the points *Q* and *R*. Join *Q C* and *R C*; these will be the single virtual eccentric arms for full forward and full backward gear respectively. Through the points *Q*, *L* and *R* describe an arc of a circle; this will contain, as in Stephenson's link-motion, the ends of all the single virtual eccentric arms; and in order to ascertain what motion the valve-spindle will derive from any given point in the link, we have only to find that point in the arc *Q L R*, which divides it in the same propor-

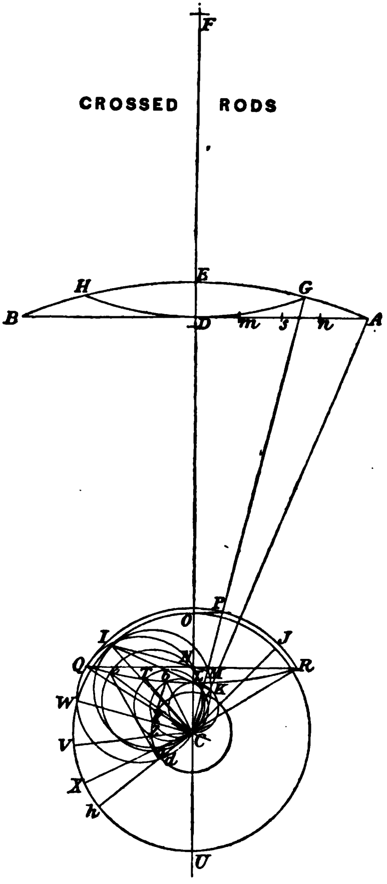


Fig. 42

tion as the given point divides the link. Now supposing that it is required to know what motion the valve-spindle would receive if the slider were at the point *S* in the link. To ascertain this, we have only to find a point *T* in the arc *QLR* which divides it in the same proportion as the given point *S* divides the link *AEB*; so that *AS* is to *SB* as *QT* is to *TR*: and join *CT*. Then *CT* will represent the throw and position of an eccentric sheave which, if connected by a rod direct on to the valve-spindle, neglecting any error due to the angular motion of the rod, would cause it to move almost exactly as it really does move under the combined influence of the real eccentrics and their oblique rods. We next have to ascertain what points in the link must be put into gear with the valve-spindle in order to cause the steam to be cut off at given positions of the crank. From the centre *C*, and with radius equal to the lap of the valve, describe the lap-circle. Draw *CW* and *CX* to represent the given positions of the crank, and let these lines cut the lap-circle in the points *Y* and *a* respectively. At these points erect perpendiculars cutting the arc *QLR* in the points *b* and *e*, and in the link *AB* find the points *m* and *n*, which will divide it in the same proportion as *b* and *e* divide the arc *QLR*; then the point *m* in the link, being brought into gear with the valve-spindle, will effect the cut-off of the steam when the crank reaches the position *CW*, and the point *n* in the link will, in like manner, cause the steam to be cut off when the crank reaches the position *CX*. Upon *CQ*, *Ce*, *CT*, *Cb*, and *CL* describe valve-circles, and through the points *Z* and *d* respectively, where the valve-circles *TZC* and *Qdc* cut the lap-circle, draw *CV* and *Ch*; then *CV* will represent the position of the crank at which the steam will be cut off when the point *S* in the link, corresponding to the point *T* in the arc *QLR*, is brought into gear with the valve-spindle, and *Ch* will represent the position of the crank at which the steam will be cut off when the link is working in full gear.

PROBLEM XXII.

The length of the link and of the radius and eccentric rods being known, and the valve-spindle put into gear with the end or any intermediate given point in the link, and the lead, the point of cut-off, and either the amount the port is to be open for a certain position of the crank, or the utmost amount that it is to be opened by this point in the link for any position whatever of the crank being given; it is required to find the throw and position of the forward and backward eccentric sheaves and the lap of the valve.

Let the straight line *A B* (Figs. 43 and 44) represent the length of the link. From the points *A* and *B* as centres, and with a radius equal to the length of the eccentric rods, describe arcs intersecting at *C;* and from the point *C* as centre, and with the same radius, describe the arc *A F B*. Bisect *A B* in *D*, and through the points *C* and *D* draw the centre line *E D C*. Set off *D E* equal to the length of the radius rod, and from the point *E* as centre, and with radius equal to *D E*, describe the arc *F D G*, cutting the arc *A F B* at the points *F* and *G*. Let *H* represent that point in the link which is required to drive the valve in accordance with the given particulars. Then by Problem III. or Problem IV., as the case may be, and in a separate diagram, we ascertain the throw and position of an eccentric sheave, which, if connected direct on to the valve-spindle by means of a rod, would drive the valve

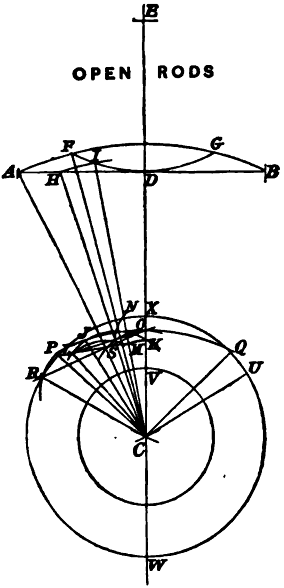


Fig.43.

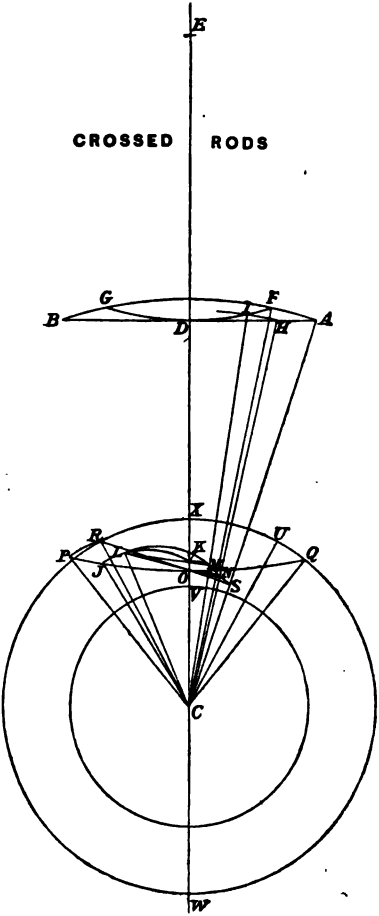


Fig.44.

in the manner required. We also, at the same time, ascertain the lap of the valve, and transfer these particulars to our link diagram (Figs. 43 and 44), making *C J* to represent the throw and position of this eccentric sheave, and *C V* equal to the lap of the valve; and from the point *C* as centre, and with a radius equal to *C V*, describe the lap-circle. From the centre *C*, and with radius *C H*, describe an arc cutting the arc *F D G* in the point *I*. Join *H C*, *F C*, and *I C*. With *J C* as a diameter describe a portion of a circle *L J K*, cutting the centre line *C D* in the point *K*, and with *K C* as a diameter describe a portion of a circle *K M*, cutting the line *I C* in the point *M*. Through the points *K* and *M* draw a straight line meeting the arc *L J K* at the point *L*. Join *L C*. With *L C* as a diameter describe a portion of a circle *L N*, cutting the line *H C* in the point *N*. Through the points *L* and *N* draw a straight line, cutting the centre line *C D* in the point *O*. Then, with its centre somewhere in the line *E W*, or in that line produced, describe an arc of a circle passing through the points *J* and *O*. Set off *O P* and *O Q* equal to each other, and each bearing the same ratio to *O J* as *D A* bears to *D H*. Join *P C* and *Q C*. With *P C* as a diameter describe the part of a circle *P R*, and with *O C* as a diameter describe the part of a circle cutting the line *A C* in the point *S*. Through the points *O* and *S* draw the line *O S R*, cutting the arc *P R* in the point *R*, and about the ntre C describe a circle passing through this point. et off XU equal to XR, and join CR and CU, hich will represent the throws of the forward and ackward eccentric sheaves and their position elative to the *real* position CW of the crank; o that if these sheaves be connected to the two ends of the link by rods of a length equal to CF, and the point H in the link be brought into gear with the valve-spindle, this point in the link being moved by the combined influence of the two eccentrics, will drive the valve *almost* exactly as it would be driven by an eccentric, CJ, connected direct on to the valve-spindle. The reason we make use of the circular arcs LK, KM, LN, &c., is simply to obtain one line at right angles to another, upon the principle of Euclid, III. 31; and the reason that the point L falls in the arc LJK is as follows:—The line KC bears the same proportion to MC as JC bears to LC; then if we were to join JK and complete the circle upon the diameter JC, the line KC would cut this circle into two unequal parts, of which the segment KLC would be the greater, and contain the two angles KJC and KLC; but (Euclid, III. 21) these angles are equal to each other, and the angle JKC, being the angle in a semicircle, is a right angle, (Euclid III. 31). For the same reason the angle KMC is a right angle; therefore the adjacent angle, LMC, must also be a right angle, and the angle *J K C* is equal to the angle *L M C*. Thus in the triangles *C J K*, *C L M*, the angle *C J K* is equal to the angle *C L M*, and the angle *J K C* is equal to the angle *L M C*; therefore the third angle *L C M* is equal to the third angle *J C K*, and the triangle *C J K* is equiangular to the triangle *C L M*. Therefore, as the side *K C* is to the side *J C*, so is the side *M C* to the side *L C* (Euclid, VI. 4); and alternately as *K C* is to *M C*, so is *J C* to *L C*, which, for the reasons we explained in the general remarks on link-motions, is the relation these lines have to bear to each other.

We would just mention that the point *L* (Figs. 43 and 44) is really the same as the point *H* (Figs. 33 and 34) in Stephenson's, and the point *G* (Figs. 39 and 40) in Gooch's link-motion; and is used in all three cases to obtain the single virtual eccentric arm for the link in mid-gear. In our Figs. (43 and 44) we have made the throws of the eccentric sheaves much larger in proportion to the length of the link, than they will ever be found to be in practice. This is done to make the points of intersection more distinct.

PROBLEM XXIII.

The length of the link and of the radius and eccentric rods being given, to find the line which contains the centre of the rocking-shaft, and the lengths of the two arms which carry the suspension links, to which the main link and radius rod are each attached.

In the straight line $A\,B$ (Fig. 45) take any point C, and at right angles to $A\,B$, draw $C\,D$ to represent half of the link. From the point D as centre, and with radius equal to the length of one of the eccentric rods, describe an arc cutting the line $A\,B$ in the point E, and from this point as a centre and with the same radius describe the arc $D\,F$. From the point C, and upon the straight line $A\,C$, set off $C\,G$ equal to the length of the radius rod, and from the point G as centre, and with the same radius, describe the arc $C\,H$, cutting the arc $D\,F$ in the point I. Join $I\,G$ and $I\,E$. The point I will represent the end of the link and of the radius rod when the link is in full gear. In the line $G\,C$, which represents the radius rod when the link is in mid-gear, determine the point of suspension J. From the point G as centre, and with radius $G\,J$, describe the arc $L\,J\,K$, meeting the

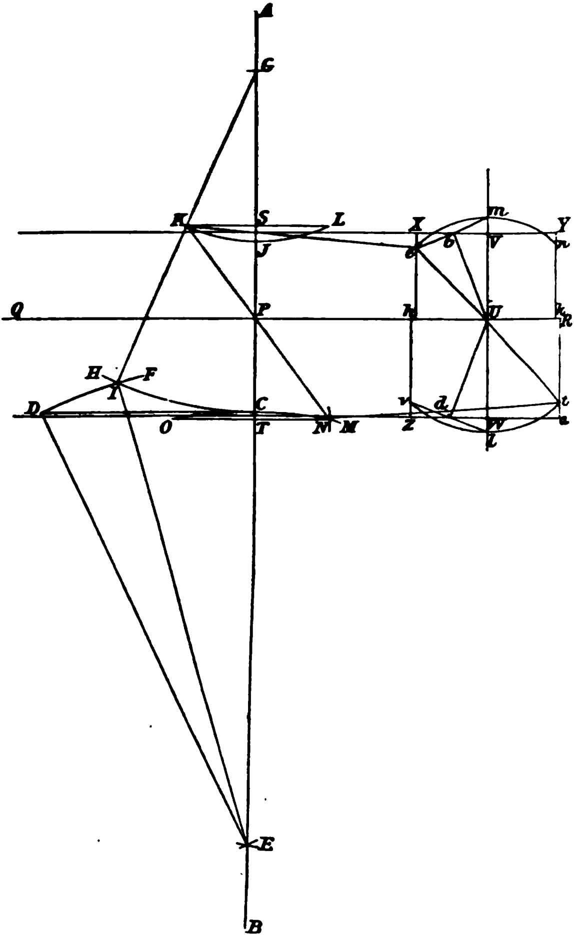


Fig. 45

ne GI in the point K, and making JL equal to K; and from the point E as centre, and with radius C, describe the arc OCM; and from the point I as entre, and with a radius equal to DC, describe an rc cutting the arc CM in the point N; and make O equal to CN. Join NK, intersecting the centre ine AB at the point P. Through this point draw the straight line QR at right angles to AB. Then the centre of the rocking-shaft, carrying the two arms from which the link and radius rod are supported, will lie somewhere in the line QR. Join KL and ON, these lines will be at right angles to the line AB, and will intersect it at the points S and T respectively. Bisect the versed sines SJ and CT, and through the points of bisection draw straight lines at right angles to AB. In the straight line QR determine the point U which is to represent the centre of the rocking-shaft, which effects the relative movements of the link and of the radius rod. Through the point U draw a straight line parallel to AB, cutting the lines which bisect the versed sines of the arcs KJL and OCN in the points V and W respectively. Set off VX and VY each equal to SK or SL, and from the points X and Y respectively, draw Xh and Yk parallel to VW. Bisect VX in b and join Ub, and through the point b draw em at right angles to Ub, cutting the perpendicular UV produced in the point m. From the point U as centre, and with radius Um, describe the arc emn, meeting the perpendicular *X h* and *Y k* in the points *e* and *n* respectively. Then *X e* will be equal to *V m*, that is, the arc *e m n* has been so drawn that its versed sine is bisected by the same line as bisects the versed sine of the corresponding arc *K J L*. In the same manner we set off *W Z* and *W a* each equal to *T O* or *T N*, and proceed to obtain the arc *v l t* meeting the perpendiculars *Z h* and *a k* at the points *v* and *t*. Join *e t*, passing through the point *U*. Then the lines *U e* and *U t* will represent the lengths of the arms of the rocking-shaft, which carry the link and radius rod respectively, and the position of the same when the link is in full gear. Join *K e* and *N t*, these lines will represent the length of the connecting links by which the arms *Ue* and *Ut* are attached to the link and radius rod.

The foregoing method of describing from a given centre an arc whose versed sine shall be bisected by a given line, will often be found useful in designing engine work, and as it may sometimes happen that the radius is known, but not the centre from which the arc is to be described, we will take the opportunity of showing how this is to be ascertained.

Let *A B* (Fig. 46) be the line which is to bisect the versed sine of the arc, and let *C D* represent the length of the chord of the arc. Bisect *C D* in *E*, and through this point draw *F G* perpendicular to *C D*. Bisect *C E* in the point *H*, and from this point as centre, and with radius equal to half the given radius of the larger arc, describe an arc cutting the line *F G* in the point *I*, and from this point *I* as a centre, and with the same radius, describe the semicircle *J H K*, passing through the point *H* and cutting the line *F G* in the points *J* and *K*. Then the point *K* will be the centre from which the arc is to be described with the radius *K J*, equal to the given radius. Through the point *K* draw the straight line

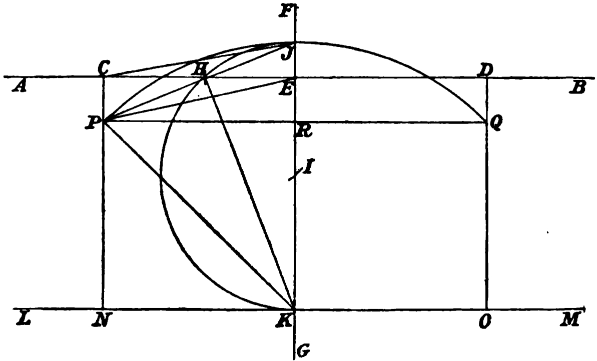


Fig. 46

L M parallel to *A B*, and draw *C N* and *D O* parallel to *F G*. From the point *K* as centre, and with radius *K J* equal to the given radius, describe the arc *P J Q* meeting the lines *C N* and *D O* at the points *P* and *Q* respectively. Then *C P* and *D Q* will each be equal to *J E*. The proof is the same for both cases (Figs. 45 and 46), we need therefore only take the one (Fig. 46) in which we have the separate diagram. Join *CJ*, *PJ*, and *PE*, also *HK*, *PK*, and *PQ*. Then in the triangles *CHP*, *JHE*, we have made the side *CH* equal to the side *HE*, and the angle *CHP* is equal to the vertical opposite angle *JHE*; and because *CP* has been drawn parallel to *JE* and *PJ* meets them, the alternate angle *CPJ* is equal to the alternate angle *PJE*: therefore the triangle *CHP* is equal to the triangle *JHE*, and the side *CP* is equal to the side *JE*; but *ER* is equal to *CP*, therefore *ER* is also equal to *JE*; but *JE* plus *ER*, that is *JR*, is the versed sine of the arc *PJQ*, from which it is clear that the versed sine of the arc is bisected by the line *AB* passing through the point *E*. Again we can show that *KP* and *KJ* are radii of the same circle. In the triangles *KHP*, *KHJ* we have the side *PH* equal to the side *HJ*, because they are the sides opposite to the equal angles in the equal triangles *CHP* and *JHE*, and we have the side *HK* common to the two triangles *KHP*, *KHJ*, and the angle *KHP* equal to the angle *KHJ*, because they are both right angles (Euc. III. 31), the angle *KHJ* being the angle in a semi-circle (in the first case (Fig. 45) *em* was drawn at right angles to *Ub*); therefore the triangle *KHP* is equal to the triangle *KHJ*, and the side *KP* is equal to the side *KJ*.

STEPHENSON'S AND ALLAN'S LINK-MOTIONS.

EQUALISING THE LEAD.

PROBLEM XXIV.

We have already pointed out in Stephenson's link-motion (Figs. 31, 32) as also in Allan's (Figs 41, 42) that the lead varies more and more as the valve-spindle is brought into gear with points nearer the centre of the link; and although with rods and links of the same lengths in both cases, the variation is less with Allan's than with Stephenson's arrangement, still, as in the former link-motion, two sets of rods have to be provided for within the distance between the crank-shaft and steam-chest, the lengths of the eccentric rods when Allan's combination is used, are considerably shorter in proportion than they would be with Stephenson's; hence, as a matter of fact, in practice the variation in lead is nearly, if not quite, as great, whether a Stephenson or an Allan arrangement be adopted. There is, however, a method at present in use which enables us to a great extent to get over this difficulty, but only for *one* motion of the engine, and that at the expense of the *reverse* motion. Thus if we equalise the lead for the *forward* motion, we make the distribution of the steam so much the more imperfect when the engine is running *backwards*. In engines, however, which are only occasionally reversed, and that for comparatively short periods, this defect in the backward motion is not of much consequence, and we can afford to improve the valve-gear for the forward motion at the expense of that in the reverse direction.

If we refer to our diagrams (Figs. 31, 32, 41, and 42), we find that the various valve-circles intersect at points of which the point of intersection of the full gear and middle gear valve-circles forms, as it were, a mean: therefore to equalise the lead for the forward gear, we shift our two eccentrics round so that this point falls in the centre line *C D*, while the crank remains at its dead-point furthest from the cylinder. This being done, we find that while we have to a certain extent equalised the lead, we have also altered it, and have at the same time caused the cut-off to take place at a different position of the crank, and this alteration in the lead would have to be compensated for by altering the lap of the valve; this again would vary the amount the ports are opened, and still further affect the position of the crank at which the ut-off takes place, so that it becomes necessary to ake all this into consideration in designing the valve-ear from the first; the method, however, of doing his differs in the Stephenson and Allan combinations; ve must therefore deal with them separately.

With Stephenson's link-motion, which is the simpler case of the two, the centre line *A C* (Figs. 31 and 32) passes through *H*, the point of intersection of the full gear and middle gear valve-circles, because *F I* (Fig. 31) and *F H* (Fig. 32) were drawn at right angles to *A C*, and the angles *F H C* and *I H C* are right angles in the two intersecting semi-circles *F H C* and *I H C*, therefore these semi-circles intersect at the point where the two right angles are formed, that is in the point *H* where the line *A C* intersects the line drawn through *F* and *H*. We have therefore in all cases of Stephenson's link-motion only to shift the sheaves through an angle equal to *A C D* in order to equalise the lead. With open rods we shift the sheaves in the direction the engine is to run with the equalised lead, but with crossed rods we shift them in the reverse direction; hence, with *crossed* rods an equalised lead may be obtained for both the forward and the backward motion of the engine by making the sheaves free to turn together between stops on the shaft through an angle in each direction equal to *A C D*, the very reversal of the engine thus equalising the lead in the opposite direction. In designing a Stephenson link-motion with equalised lead we proceed exactly as stated in Problems XVII. and XVIII., except that when we have found *C F* in the former, or *C H* in the latter, according to the circumstances of the case (see * p. 130 or p. 136) we transfer it to our link-diagram, setting it *back* from *C D* for open rods, and *forward* toward *C D* for crossed rods through an angle in each case equal to *A C D*, greater or less than the angle which *C F* or *C H* should really make with the centre line *C D*, as found by Problems III. or IV., as the case may be; having done this we complete the diagram as in Problem XVII. or XVIII., and then we turn the eccentric arms with the curve of centres, and any single virtual eccentric arms we may have found, back again through the same angle *A C D*, so that *C F* or *C H* occupies its correct position with regard to the centre line *C D*. The centre line, *C D*, will then be found to pass through the point, in which the full gear and middle gear valve-circles will intersect.

In Allan's link-motion the angle through which *C F* or *C H* has to be set back or forward cannot be so easily ascertained, as it is dependent upon the arrangement of the several details of each combination, which renders the investigation more intricate; the following construction, however, will give the angle required.

In Problem XXII. we showed how to get out an Allan valve-gear which would yield results in accordance with certain requirements, but in that case the valve was to have the same lead for similar relative positions of the link and slider in forward and backward gear: we now have to design a valve-gear under precisely similar conditions as those given in Problem XXII., but with the sheaves so set as to give comparatively equal lead in one direction of motion of the engine.

Let *A B* (Figs. 47 and 48) represent the throw of the single virtual eccentric arm and its position relative to the real position *A C* of the crank, so that if it were connected direct on to the valve-spindle by means of an eccentric rod, it would drive the valve in the same manner in which it is required that it shall be driven by the point *H* in the link (Figs. 43 and 44). This can be obtained by either Problem III. or IV., according to circumstances, as already explained in Problem XXII. Produce *C A* to *H*. With *B A* (Figs. 47 and 48) as a diameter describe the arc of a circle *B D* and draw *A D*, making the angle *B A D* equal to the angle *I C D* (Figs. 43 and 44). This line *A D* is drawn below *A B* with open rods, and above *A B* when cross rods are used; then the point *D* (Figs. 47 and 48) will correspond with the point *L* (Figs. 43 and 44); and as in those figures a line drawn from this point and at right angles to *C H* will pass through the point *O*, and we know the angle *H C O*, therefore with open rods (Fig. 43) the angle *L O C* must be equal to a right angle *minus* the angle *H C O*, for *L O* being at right angles to CH, the third angle ONC of the triangle

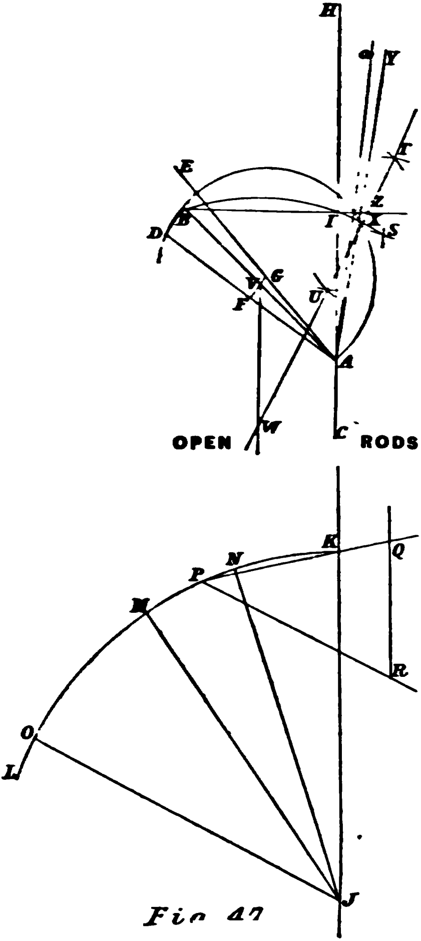


Fig. 47

N C is a right ngle. Again, with rossed rods (Fig. 44), the angle *LOC* is equal to a right angle *plus* the angle *H C O*; hence, in either case, if we describe upon the line *L C* an arc of a circle, which shall contain the required angle *LOC* (Euclid, III. 33), the point *O* must fall somewhere on that arc. Draw *A E* (Figs. 47 and 48), making the angle *D A E* equal to the known angle *H C O* (Figs. 43 and 44); this line *A E* is drawn above *A D* with open rods, and below it when crossed rods are used. Bisect *A D* in *F*, and draw *F G* at right angles to

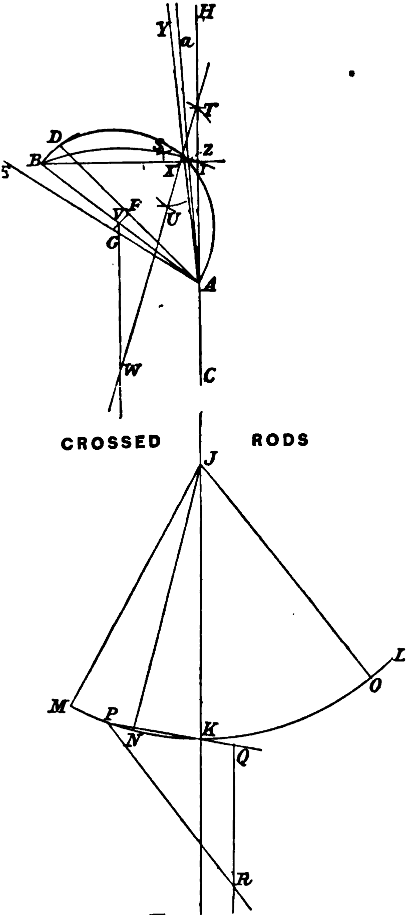


Fig. 48.

A D, cutting *A E* in the point *G*. From this point as a centre, and with *G A* as radius, describe the arc *D X A*, and from the point *B* draw *B I* perpendicular to *H A* and meeting it in the point *I*.

From any point *J* (lower portion of figures) as centre, and with a convenient radius, describe the arc *K L* (Fig. 47), *M L* (Fig. 48), and take a portion of this *K M* and bisect *K M* in *N*. Join *N J*, and set off the angle *N J O* equal to the known angle *B A H*. In the arc *M K* take a point *P* which divides it in the same proportion as the given point in the link divides the link, the proportion being in each case taken from similar ends of the arc *M K* and the link *A B*. Join *P K* and produce it, and draw *P R* parallel to *J O*, and from the point *P* set off *P R* equal to *A B*, and from the point *R* draw *R Q* parallel to *J K*, and cutting the line *P K* produced in the point *Q*. From the points *B* and *A* as centres, and with *P Q* and *R Q* respectively as radii, describe arcs intersecting at the point *S*. If we now describe the arc of a circle passing through the three points *B*, *I*, and *S*, this arc will cut the arc *D X A* in the required point *X*. This is conveniently done as follows. With the points *I* and *S* as centres, and with any radius, describe arcs intersecting in the points *T* and *U* respectively. Join *T U* and produce it, and from the point *V*, where the line *F G* bisects the line *A B* passing through the centre from which the arc *B D* was struck, draw *V W* parallel to *HA*, and intersecting the line *TU* produced in the point *W*. This point will be the centre from which the arc that will pass through the three points *B*, *I*, and *S* has to be described. From the point *W* as centre, and with radius equal to the distance *WB*, describe the arc *BSI*, cutting the arc *DXA* in the point *X*, which will be the point required. Join *AX* and produce it towards *Y*, then the angle *YAH* is the angle through which we have to shift the sheaves in order to equalise the lead. With open rods we shift the sheaves in the direction the engine is to run with the equalised lead, but with crossed rods we shift them in the reverse direction; hence, as in Stephenson's link-motion, an equalised lead may be obtained for both the forward and backward motion of the engine by using crossed rods, and making the sheaves free to turn together between stops on the shaft through an angle in each direction equal to *YAH*, the very reversing of the engine thus equalising the lead for the opposite direction of motion of the crank. The curve *BSI* is, *strictly* speaking, not an arc of a circle, though it so *very* closely approximates to one that it may, under any circumstances, be considered as a true circular arc; nevertheless, where extreme accuracy is required, it is desirable to obtain the point *S*, so that it shall be at no great distance from where the point of intersection of the curve *BSI* with the arc *DXA* will take place. But as this cannot always be settled with any certainty beforehand, we may first take the point *S* wherever the construction may fix it; and if it falls at too great a distance from where the arc described through the points *B*, *S*, and *I* cuts the arc *D X A*, we can reconstruct the lower half of our figure, making the angle *K J M* equal to twice the angle *X A I*, as given by the preliminary construction. This will give a point *S* *almost* exactly coinciding with the point *X*.

In our two diagrams (Figs. 47 and 48) we have taken the arcs *K L* (Fig. 47) and *M L* (Fig. 48) as having their concave sides towards the same direction as those of the curves of centres would be. Thus, with open rods (Fig. 47), the arc *K L* has its concave side towards the point *R*, representing the centre of the shaft; and with crossed rods (Fig. 48) the arc *M L* has its concave side away from this point. There is, however, no direct connection between these arcs and the corresponding curves of centres, and we have only taken the arcs in these respective positions to enable the point *X* in each case to fall *between* the points *I* and *S* for the purpose of ensuring perhaps greater accuracy in determining the point *X* itself. If the point *S*, is required to fall somewhere beyond the point *I* (Fig. 47), then the arc *K L* must be *concave* towards the point *R;* but if we want the point *S* to fall between the points *B* and *I* (Fig. 48), we must invert the arc *M L*, so that its *convex* side shall face *R*. In either case, however, it will be seen that the point *S may* happen to fall between *X* and *I*, which is not desirable, as *S* and *I* would then be so close together as to make it difficult to ascertain the true position of the centre from which to describe the arc *B S I*. This may be avoided by making the angle *M J K*, in both cases, large enough; or, where this is not easy to determine beforehand, we may first find the point *X* approximately, and then reconstruct the lower half of our diagram, as before explained, and find *X* with the greatest accuracy. We have only to bear in mind that with *open* rods the angle *B A S* is the given angle *B A I plus* half the assumed angle *K J M*, and with *crossed* rods it is the angle *B A I minus* half this assumed angle. The foregoing construction applies to cases in which *A B* represents the single virtual eccentric arm, referring to an intermediate point in the link; where, however, *A B*, corresponding to *C P* (Figs. 43 and 44), represents the single virtual eccentric arm referring to either *end* of the link, our construction is as follows. With *B A* (Figs. 47 and 48) as a diameter, describe the arc of a circle *B D* and draw *A D*, making the angle *B A D* equal to the angle *F C D* (Figs. 43 and 44); this line is drawn below *A B* with open rods, and above *A B* when crossed rods are used, then *A D* will correspond with *C R* (Figs. 43 and 44). Upon *A D* as a diameter describe an arc of a circle (Euclid, III. 33) which shall contain an angle equal to the angle *R O C* (Figs. 43 and 44), which, as we have already explained, is for *open* rods, equal to a right angle *minus* the angle *A C D*, and for *crossed* rods to a right angle *plus* the angle *A C D*. Draw *A E* (Figs. 47 and 48), making the angle *D A E* equal to the known angle *A C D* (Figs. 47 and 48). This line *A E* is drawn *above* *A D* with *open* rods, and *below* it when *crossed* rods are used. From the point *B* draw *B Z* at right angles to *A H*, and cutting the arc *D X A* at the point *Z*. From the point *A* draw *A a*, passing through this point. Then the angle *H A a* is the angle through which we have now to shift the sheaves in order to equalise the lead, as already explained in the previous case.

In designing an Allan link-motion with equalised lead we proceed exactly as stated in Problem XXII., except that when we have found by Problem III. or IV. the length of *C J*, and its position relative to *C D*, we transfer it to our link diagram, setting it *back from* *C D* for open rods, and *forward towards* *C D* for crossed rods, through an angle in either case equal to *Y A H* (Figs. 47 and 48), greater or less, as the case may be, than the angle *J C D* (Figs. 43 and 44). We then complete the diagram as set forth in Problem XXII., and turn the eccentric arms with the curve of centres, and any single virtual eccentric arms we may have found, back again through the same angle *Y A H;* so that *C J* occupies its correct position with regard to *C D*, and *C D* will then be found to pass through the point at which the full gear and middle gear valve-circles intersect.

In our Figs. (47 and 48) the line *T W* appears to pass through the required point *X;* it does not, however, necessarily do so.

LINK EXPANSION-GEARS.

We have already pointed out how expansion-gearing may be made variable either by shifting the eccentric sheave or by altering the lap of the cut-off valve; but we have now to deal with expansion-gearing in which the cut-off valve is driven by an intermediate link in the same way as the main valve is driven in reversing combinations. There is, however, this great difference in the link itself: that used in expansion-gearing corresponding to only one-half of a link, such as is used in reversing combinations, and it has, besides, only an eccentric rod attached to one end of it, the other being dealt with in the case of Stephenson's and Allan's links in a different manner from that in which it is treated in Gooch's. In the two former this end of the link, which corresponds to the centre point of a reversing link, is either attached to a rod similar to an eccentric rod, the strap of which embraces a sheave not *eccentric to* but *concentric with* the crank-shaft, or it is attached to a block sliding in a slot curved to an arc of a circle struck from the centre of the crank-shaft; and in either case its position relative to the valve-spindle is changed in the same manner as in the corresponding link-reversing motion, the attachment to the link for that purpose being at its fixed end, which in all three forms of link virtually corresponds with the centre point of a link in a similar *reversing-gear*, and when the eccentrics are set so as to give that point no appreciable movement, which is the case when the valve has neither lap nor lead. In the case of a Gooch's link being used, the eccentric rod is attached to one end of the link, while the other is carried by a fixed stud.

EXPANSION GEAR WITH STEPHENSON'S LINK.

PROBLEM XXV.

Given the length of the link and of the eccentric rod and the throw of the sheave; it is required to find what motion the expansion-valve will receive from any point in the link. And conversely, given the length of the link and of the eccentric rod, and the travel which the valve is to receive from any given point in the link; it is required to find the throw of the eccentric sheave.

In the straight line *A B* (Fig. 49) take any point *C*, and with this point as centre, and with a radius equal to the length of the eccentric rod, describe the arc *D F*, making *D E* and *E F* each equal to the length of the link. Join *D C* and *F C*. From the centre *C*, and with radius equal to the throw of the eccentric sheave, describe the circle *G B H*. From the point *C* draw *C G* at right angles to *C D*, and with a centre somewhere in the line *A B* describe an arc of a circle passing through the points *G* and *C*. Having now obtained the curve of centres *G K C*, we ascertain by

Problem XIV. the position of the expansion eccentric

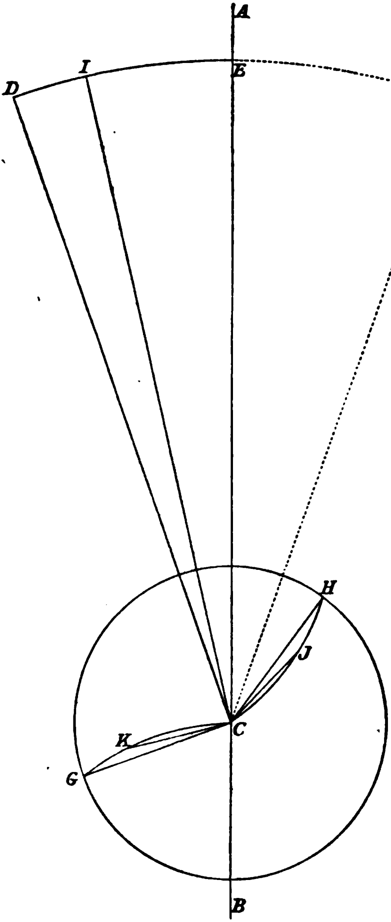


Fig. 49.

sheave relative to the *real* position of the crank, and we draw *C H* in that position, and describe the curve of centres *H J C* with the same radius as we described the arc *G K C.* Then, if we wish to ascertain what motion any point *I* in the link will transfer to the valve-spindle, we have only to take a point *J* in the arc *C J H,* which divides it in the same proportion as the point *I* divides the link (the proportion being taken in each case from the centre *C* and the end *E* of the link), and join *C J.* The line *C J* will represent the throw and position of the single virtual eccentric arm, which, if connected direct on to the valve-spindle by an eccentric rod, would cause the valve to travel *almost* exactly as it actually does travel under the influence of the real eccentric *C H* and the link *D E.* The end *E* of the link has no travel, but is attached to a rod, *E C,* similar to the eccentric rod and of the same length; but the strap at the end *C* is not attached to an eccentric sheave, but embraces the shaft, a journal being formed on it for that purpose. But as there is in that case continual wear going on as the shaft revolves, the end *C* of the rod *E C* is sometimes held by a stud fixed on to some part of the framing as near to the shaft as possible. In other cases, the rod *E C* is dispensed with, and the end *E* of the link is carried by a block sliding in a slot curved to an arc struck from *C,* the centre of the shaft. In either case the link is shifted into different positions by a connecting link, one end of which is attached to the point *E* of the expansion-link, the other being carried by a lever or screw-gear. The dotted lines *E F* and *F C* represent the link and rod when the link is in full gear.

We now come to the converse case, in which *any point in the link being given, and the motion the valve-spindle is to receive when that point is brought into gear with it, we have to find the throw and position of the eccentric sheave.*

Let *I* be the given point in the link, and *C J* represent the throw and position of an eccentric sheave which would give the required motion to the valve. This may be ascertained by either Problem VII., XI., XII., or XV. Join *C I* and draw *C K* equal to *C J* and at right angles to *C I*: and with a centre somewhere in the line *A B* describe the arc of a circle passing through the points *K* and *C*, and continue this arc to *G*, so as to make *K G* bear the same proportion to *K C* as *D I* bears to *I E*. Join *C G*. From the centre *C*, and with radius *C G*, describe the circle *G B H*. Through the points *C* and *J*, and with the same radius as that with which we just described the arc *G K C*, describe the arc *C J H*, cutting the circle *G B H* in the point *H*. Join *C H*. Then *C H* will represent the throw and position of the real eccentric arm, which, if attached by a rod *C D* to the point *D* of the link, would cause the given point *I* to impart to the valve-spindle, when brought into gear with that point, a motion *almost* exactly similar to that which it would receive if driven direct by the given eccentric arm *CJ*.

In order to make the matter quite clear, we have shown (p. 204, Fig. 52) how the full expansion diagram is set out when Stephenson's or Allan's link is used.

EXPANSION GEAR WITH GOOCH'S LINK.

PROBLEM XXVI.

Given the length of the link and of the eccentric and radius rods and the throw of the sheave; it is required to find what motion the expansion valve will receive from any point in the link. And conversely, given the length of the link and of the eccentric and radius rods, and the travel which the valve is to receive from any given point in the link; it is required to find the throw of the eccentric sheave.

Let the arc *A B* (Fig. 50), struck from the centre *C* with radius equal to the radius rod *C A*, represent the link; bisect *A B* in *D*. Join *C D* and produce it; from the point *A* as centre, and with radius equal to the length of the eccentric rod, describe an arc cutting the line *C D* produced in the point *E*. Join *A E*; and from the point *E* as centre, and with radius equal to the given throw of the eccentric sheave, describe the circle *F G H*, and draw *E F* at right angles to *E A*. At the point *G*, where the circle *F K H* cuts the centre line *D E*, draw *G I* at right angles to *D E*, and cutting the line *E A* at the point *I*. From the centre *E*, and with *E I* as radius, describe the arc *I J;* and from the point *E* draw *E J* at right angles to *D E*, and meeting the arc *I J* in the point *J*, then the angle *JEF* will be equal to the angle *I E G;* and, as in Gooch's reversing link-motion, the line *E J* represents the throw and position of the single virtual eccentric arm, referring to the motion of the valve spindle when the link is in full gear, at the same time the line *E J* is the line containing the ends of all the single virtual eccentric arms, and as each of these arms will be drawn from the point *E*, the line *E J* will contain not only the

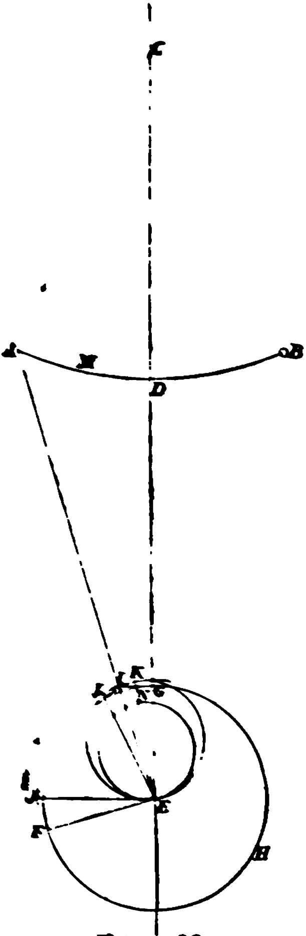


Fig. 50.

ends but the arms themselves. Having now obtained this line *E J*, we ascertain by Problem XIV. the position of the expansion eccentric sheave relative to the *real* position of the crank, and we draw *E K* in that position and *E L* in the same relative position to *E K* that *E F* has to *E J*; then *E L* will be the position of the actual eccentric sheave relative to the *real* position of the crank. If we now wish to ascertain what motion any point *M* in the link will impart to the valve spindle, we have only to find a point *N* in the line *E K* which divides it in the same proportion as the point *M* divides the link (see p. 113), the proportion being in all cases taken from the end *B* of the link and the end *E* of the line *E K*; then *E N* will represent the throw and position of the single virtual eccentric sheave, which, if connected direct on to the valve spindle by an eccentric rod, would impart to it *almost* exactly the same motion as it receives from the point *M* in the link. With regard to the method of carrying the link, as in Gooch's arrangement the link itself is not shifted with reference to the valve spindle, and the end *B* of the link receives no motion from the eccentric, this point in link-expansion motions is carried by a stud fixed on to the framing of the engine, and the radius rod *C A* is shifted relative to the link by the same means as are adopted with Gooch's reversing link motion, either a lever or screw-gear being used.

We now come to the converse case, in which *any* *point in the link being given, and the motion which the valve spindle is to receive when that point is brought into gear with it; to find the throw and position of the actual eccentric sheave.* Let *M* be the given point in the link, and let *E N* represent the throw and position of an eccentric sheave, which, if connected by an eccentric rod direct on to the valve spindle, would give it a motion similar to that which it is required to be given to it by the point *M* in the link; this may be obtained by either Problem VII., XI., XII., or XV. Produce *E N* to *K*, making *N K* to bear the same proportion to *N E* as *M A* bears to *M B*, then *E K* will represent the single virtual eccentric arm referring to the travel of the valve spindle, when the link is brought into full gear. We have now to find the throw and position of the actual eccentric arm and its position relative to the real position of the crank. Upon *E K* as a diameter describe a circle, and draw *E L* meeting the circle, and making the angle *L E K* equal to the angle *I E G*. Then *L E* will represent the throw and position of the actual eccentric sheave required. In order to show how this problem is applied we have set out a full expansion diagram for Gooch's link (see p. 208, Fig. 53).

EXPANSION GEAR WITH ALLANS LINK.

PROBLEM XXVII.

Given the length of the link and of the eccentric and radius rods and the throw of the sheave; it is required to find what motion the expansion valve will receive from any point in the link. And conversely, given the length of the link and of the eccentric and radius rods, and the travel which the valve is to receive from any given point in the link; it is required to find the throw of the eccentric sheave.

In the straight line *A B* (Fig. 51) take any point *C*, and at right angles to *A B* draw *C D* to represent the link. From the point *D* as centre, and with a radius equal to the length of the eccentric rod, describe an arc cutting *A B* in the point *E*. With this point as centre, and with a radius equal to the throw of the eccentric sheave, describe the circle *H G B*, and from the same centre, and with radius equal to the length of the eccentric rod, describe the arc *D F*. Set off *C A* equal to the length of the radius rod, and from the point *A* as centre, and with radius equal to *AC*, describe an arc cutting the arc *DF* in the point *F*. Join *FE* and *DE*, and draw *EG* at right angles to *ED*. From the point *H*, where the circle *HGB* cuts the centre line *AB*, and at right angles to *AB*, draw *HI* cutting the line *EF* in the point *I*. From the centre *E*, and with *EI* as radius, describe the circle *IJK*; draw *EJ*, making the angle *JEG* equal to the angle *FEC*, and with a centre somewhere in the line *CB* produced, describe an arc of a circle passing through the points *J* and *E*. Having now obtained the curve of centres *JOE*, we ascertain by Problem XIV. the position of the expansion eccentric sheave relative to the *real* position of the crank, and we draw *EK* in that

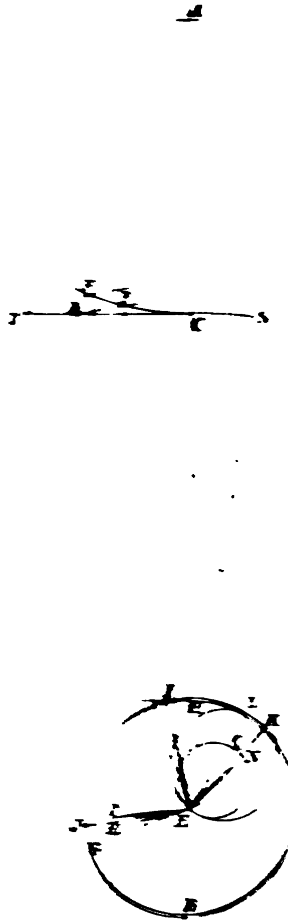


Fig 51

position, and describe the curve of centres *E N K* with the same radius as that with which we described the arc *J O E*, and we draw *E L* in the same relative position to *E K* as *E G* has to *E J;* then *E L* will be the position of the actual eccentric sheave relative to the *real* position *E B* of the crank. If we now wish to ascertain what motion any point *M* in the link will impart to the valve spindle, we have only to find a point *N* in the arc *E N K* which divides it in the same proportion as the point *M* divides the link, the proportion being in every case taken from the end *C* of the link and the end *E* of the arc. Join *E N;* the line *E N* will represent the throw and position of the single virtual eccentric arm, which, if connected direct on to the valve spindle by an eccentric rod, would cause it to travel *almost* exactly as it actually does travel under the influence of the real eccentric *E L* and the link *D C,* when the point *M* is brought into gear with the valve spindle. The end *C* of the link has no travel, but is connected to a rod, *C E,* similar to an eccentric rod, but of a shorter length, the proportion being as *C E* is to *D E,* the strap of which rod, however, is not attached to an eccentric sheave, but embraces the shaft, a journal being formed on the latter to receive it; but as there is in that case, as we pointed out with regard to Stephenson's arrangement, continual wear going on as the shaft revolves, the end of the rod *C E* is sometimes held by a stud fixed on to the framing as near to the shaft as possible; in other cases this rod is dispensed with, and the end C of the link is carried by a block sliding in a slot curved to an arc struck from E the centre of the shaft. In either case the link and radius rod are shifted relative to each other in the manner explained in Problem XXIII.

We now come to the converse case, in which *any point in the link being given, and the motion the valve spindle is to receive when that point is brought into gear with it; it is required to find the throw and position of the actual eccentric sheave.* Let the point M (Fig. 51) be the given point in the link, and let EN represent the throw and position of an eccentric sheave, which, if connected by an eccentric rod direct on to the valve spindle, would give it a motion similar to that which it is required shall be given to it by the point M in the link; this line EN may be obtained by either Problem VII., XI., XII., or XV. Join EM, and from centre E, with radius EM, describe an arc cutting the arc FC in the point P. Join PE, and upon EN as diameter describe a circle, and draw EQ, meeting this circle at the point Q, and making the angle QEN equal to the angle PEC. Draw ER equal to EQ and at right angles to EM, and draw EO equal to EN, and making the angle REO equal to the angle QEN. Then with a centre somewhere in the line CB produced, describe the arc of a circle passing through the points O and E and continue this arc on to J, making OJ

to bear the same proportion to *O E* as *D M* bears to *M C*. Join *J E*. From the centre *E*, and with radius *E J*, describe the circle *J I K*. Through the points *N* and *E*, and with the same radius as that with which we described the arc *O E*, describe the arc *E N K*, meeting the circle *J I K* at the point *K*. Join *E K*. This line *E K* will represent the single virtual eccentric arm referring to the motion of the valve spindle when the link is put into full gear. Upon *E K* as a diameter describe a circle and draw *E L*, meeting the circle at the point *L*, making the angle *K E L* equal to the angle *C E F*. Then the line *E L* will represent the throw and position of the actual eccentric sheave required.

In order to show how this problem is applied, we have set out a full expansion diagram for Allan's and Stephenson's link motions (see p. 204, Fig. 52).

STEPHENSON'S AND ALLAN'S LINK EXPANSION DIAGRAMS.

PROBLEM XXVIII.

THE APPLICATION OF THE CURVE OF CENTRES IN STEPHENSON'S AND ALLAN'S EXPANSION LINK DIAGRAMS TO AN ORDINARY EXPANSION DIAGRAM.

Let the straight lines *A B* and *C D* (Fig. 52) be perpendicular to each other and intersect at the point *E*, and let *E F* represent the throw of the main valve eccentric sheave and its position relative to the *real* position *E A* of the crank. From the centre *E*, and with radius *E F*, describe the circle *F M D*. Upon *E F* as a diameter describe the primary main valve circle. Let *E G* represent the earliest point of cut-off that will be required, and let the line *E G* cut the valve-circle *F N E* in the point *H*. Join *F H* and produce it. From the centre *E*, and with radius equal to *C H* in Stephenson's arrangement (Fig. 49), or *E K* in Allan's (Fig. 51), describe the arc of a circle cutting the line *F H* produced in the point *I*. Join *I E*. Then the line *I E* will represent the throw of the eccentric arm which virtually drives the expansion valve, when the link is put into full gear,

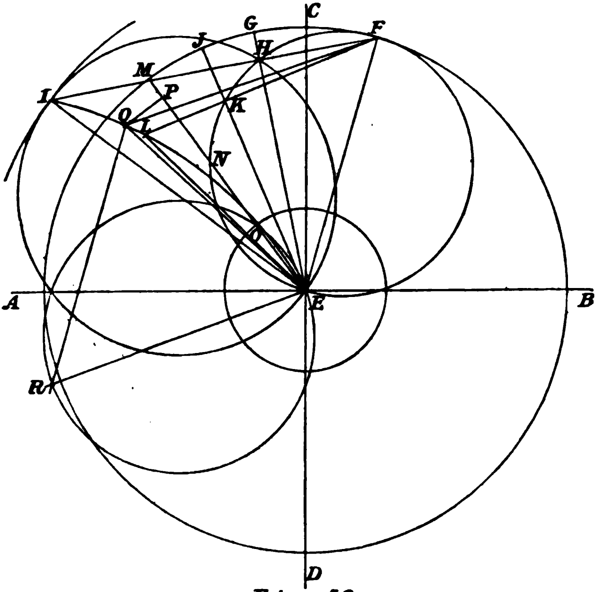


Fig. 52.

and the position of that arm relative to the *real* position *E A* of the crank; and, taking the expansion valve as having no lap either positive or negative (in which form, as we have already previously explained, it effects the sharpest cut-off of the steam), we find that when the link is put into full gear, the steam is cut off at the position *E G* of the crank, passing through the point where the primary expansion and main valve-circles intersect. If we now describe upon *I E* the curve of centres as obtained by either Problem XXV. or XXVII., we can ascertain the points in the link which will effect the cutting off of the steam at the various required positions of the crank. Let it be required to find any points in the link which will cut off the steam when the crank reaches such a position as *J E*, cutting the main valve-circle in the point *K*. From the point *F* draw a line through this point, and cutting the curve of centres in the point *L*: we have then only to find a point in the link which will divide it in the same proportion as the point *L* divides the curve of centres, and this will be the point in the link which will effect the cut-off of the steam at the corresponding required position of the crank.

Since we have taken the valve as having no lap, the simple intersection of the primary main valve-circle with the several expansion circles gives us the respective points through which the centre line of the crank passes when the expansion valve closes the steam-port; if, however, the valve has any lap either positive or negative, from the centre *E* and with the amount of lap as radius describe the lap-circle. Draw *E M* to represent the position of the crank at which it is required that the steam shall be cut off, and let *E M* cut the main valve-circle in the point *N*. Set off *NP* equal to *E O*; and at the point *P*, and perpendicular to *E M*, draw a line cutting the curve of centres at the point *Q*. Join *Q F*, and draw *E R* parallel to it; also draw *Q R* parallel to *F E*, and cutting *E R* in the point *R*. Upon *E R* describe the resultant circle which will pass through *O*, the point of intersection of the lap-circle and the line *M E*. Hence the point in the link which will effect the cut-off of the steam at the position *E M* of the crank is that point which divides it in the same proportion as *Q* divides the curve of centres *I L E*. In the present case (Fig. 52) we have taken the expansion sheave as *following* that of the main valve: this is done because the points of cut-off are, so to speak, behind *E F*, the centre line of the main valve eccentric sheave, therefore the main valve is travelling from right to left when the cut-off is taking place; and in order that this cut-off may be as sharp as possible, we place the expansion eccentric sheave so that the expansion valve shall effect the same when it is travelling in a direction opposite to that of the main valve. And as in the present case the expansion valve cuts off the steam when the main valve itself is closing the port in the cylinder, or at least moving in the direction to do so, while the expansion valve is moving in the opposite direction, it is clear that the expansion valve must be made either with ports through it, or at any rate so that the cut-off edges, as it were, follow the valve.

GOOCH'S LINK EXPANSION DIAGRAM.

PROBLEM XXIX.

THE APPLICATION OF THE LINE OF CENTRES IN GOOCH'S EXPANSION LINK DIAGRAM TO AN ORDINARY EXPANSION DIAGRAM.

Let the straight lines *A B*, *C D* (Fig. 53), be at right angles to each other and intersect at the point *E*, and let *E F* represent the throw of the main valve eccentric sheave and its position relative to the *real* position, *E A*, of the crank. From the centre *E*, and with radius *E F*, describe the circle *F O G*. Let the expansion valve have a negative lap, and from the centre *E* with this lap as radius, describe the lap-circle, and let *E H* represent the position of the crank, at which it is required that the cut-off shall take place when the link is in full gear, and let the line *E H* cut the circle upon *F E* in the point *J*. Set off *J K* equal to *E I* the radius of the lap-circle, and at the point *K* draw *K L* perpendicular to *E H*, and from the centre *E*, and with radius *E L*, equal to *E K*, ascertained by Problem XXVI. (Fig. 50), describe an arc of a circle cutting *K L* in the point *L*. Join *L E*, then *L E* will represent the line of centres

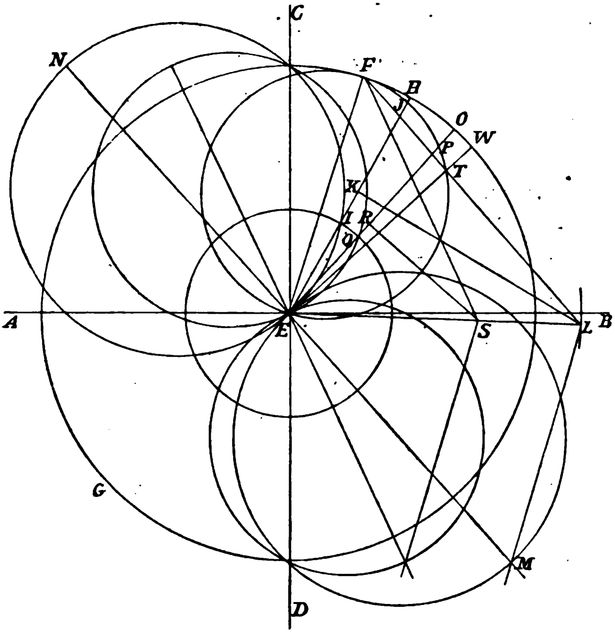


Fig. 53

E K (Fig. 50), and it will also represent the single virtual expansion full-gear eccentric arm. Join *F L* and draw *E M* parallel to it, and *L M* parallel to *E F*, and cutting the line *E M* at the point *M*, then the line *E M* will be the diameter of the primary resultant circle. Produce *M E* to *N*, making *E N* equal to *E M*, and upon *M E* and *E N* as diameters describe circles; these will be the primary and secondary resultant circles respectively, and the secondary resultant circle will cut the lap-circle in the same point *I* in which it cuts or is cut by the line *E H*; hence the expansion valve closes the port in the main valve, and cuts off the steam, when the crank reaches the position *E H* as was required. Similarly we can find the intermediate points in the line of centres *E L*, which will cause the steam to be cut off in other given positions of the crank. Let it be required, for instance, that the steam shall be cut off when the crank reaches such a position as *E O*, intersecting the main valve-circle at the point *P*. From *P* set off *P R* equal to *E Q* the radius of the lap-circle, and at the point *R* erect a perpendicular to *E O*, meeting the line of centres in the point *S*, then *E S* will represent the single virtual expansion eccentric arm which will effect the cut-off of the steam at the position *E O* of the crank; and to satisfy ourselves of this, we have only to construct the corresponding resultant circles, the secondary one of which will pass through the point *Q* in which the lap-circle and the line *E O* already intersect. In the present case we have taken the expansion valve as having negative lap, but we can still more easily determine the position of, and the points in, the line of centres *E L*, if we consider the expansion valve as having no lap at all, and require that when the expansion link is in full gear, the cut-off of the steam shall take place when the crank reaches such a position as *E W* intersecting the main valve-circle in the point *T;* we have then only to join *F T* and produce it till it cuts or is cut by the arc described from the centre *E* with radius *E L,* equal to *E K* (Fig. 50) and join *E L;* similarly we can find any other single virtual expansion eccentric arm in the line *E L.* In any case, however, whether the expansion valve has lap or not, having found the required points in the line of centres *E L,* we find the corresponding points in the link which divide it in the same proportion in which the points found in the line of centres divide that line, the proportion being in every case taken from the end *E* of the line of centres and the end of the link which is fixed. It is clear that the same results as the foregoing can be obtained, without the use of a link combination, by adopting, instead, some means by which the actual throw of the expansion eccentric sheave itself can be varied, either by hand-worked gear or by the action of a governor.

REVERSING WITH SHIFTING ECCENTRIC.

PROBLEM XXX.

This reversing gear is made in several forms, the simplest of which is perhaps that with the eccentric sheave loose upon the shaft, and free to revolve round the shaft through a given angle between fixed stops, against either of which it is kept by the resistance of the slide-valve; and the reversal of the engine is effected by disconnecting the eccentric rod from the valve spindle and working the valve by a hand lever just sufficient to start the crank-shaft revolving in the opposite direction, and to bring the other stop into gear with the eccentric sheave, when the eccentric rod is either thrown or throws itself into gear again with the valve spindle, and the engine continues to work in the reverse direction. Most of the engines of the penny steamers which ply on the river Thames are reversed in this way. In another arrangement of this form of reversing gear, the eccentric sheave is caused to revolve round the shaft through the given angle and at a speed greater than that at which the shaft itself is revolving, it thus overtakes the shaft as it were, and comes into gear with the stop, which applies to the reverse motion of the engine; the motion of the valve is thus reversed, and the crank commences to revolve in the opposite direction, and the stop, which was previously overtaken by the eccentric sheave, is now driving that sheave before it, hence there is no danger of the engine again reversing itself. There are several arrangements for causing the sheave to overtake the shaft, such as the loose sleeve and screw gear, but which it is beyond the province of the present treatise to go into; all we have to determine at present is the angle through which the sheave has to be shifted, in order to reverse the motion of the engine.

Let the straight lines *A B*, *C D* (Fig. 54), be at right angles to each other and intersect at the point *E*. By Problem III. or IV. we ascertain the throw of the eccentric sheave for the forward and backward motion of the engine respectively, and its position in each case relative to the *real* position *E A* of the crank. From the point *E* as centre, and with radius equal to the throw of the sheave, describe the circle *A C B D*, and draw *E F* and *E G*, making the angles *C E F* and *D E G* each equal to the ascertained angle of advance.

Then the angle *FEG* will be the angle through which the sheave must revolve upon the shaft in order that the engine may run in the reverse direction.

There is another form of reversing gear with shifting eccentric, known as the "Wedge motion gear," in which, instead of the sheave being arranged to revolve partly round the shaft, it is made with an oblong slot through it, the sides of which fit on two flat

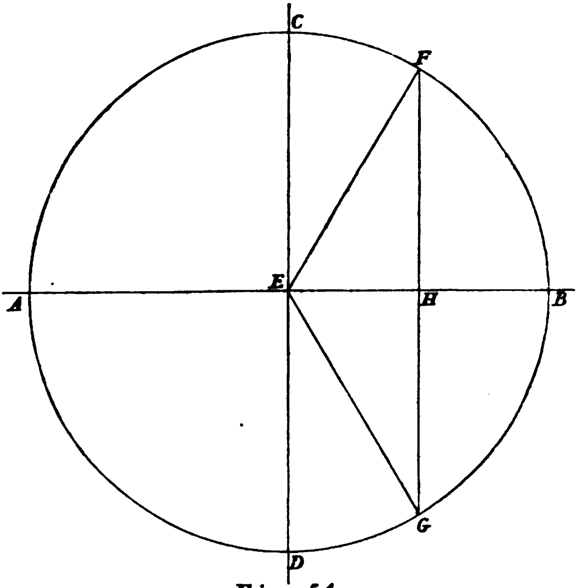


Fig. 54.

sliding faces on the shaft itself, so that the sheave can be moved in a direction parallel to *F G* in a plane at right angles to the axis of the shaft, through a limited distance, while at all times it must revolve with the shaft. The centre line of the slot has to be a distance *E H* (Fig. 54) from the true centre of the eccentric, and the length of this slot must be such that the sheave can be shifted at right angles to the axis of the shaft, through a distance *F H* or *H G* in each direction from its middle position. Hence if we consider the point *E* to represent the true centre of the sheave, then the line *F G* will represent the relative position and direction of the slot and the distance through which the sheave itself must be capable of being slidden, in order to put the engine from full gear in the one direction, into full gear in the other, the total length of the slot itself being greater than *F G* by an amount equal to the space taken up by the shaft and the two wedges; this additional length being set off equally in the direction *H F* and the direction *H G*, the point *H* thus remaining the centre of the slot. In practice this shifting of the sheave is effected by sliding wedges working in grooves in the shaft, one at each end of the slot, which, as we have just explained, is made of extra length to admit them without diminishing the amount the sheave has to slide. These wedges are set with their ends reversed, and they are connected by suitable gearing with the reversing lever or screw.

APPENDIX TO PROBLEM XV.

Having obtained the particulars for the main valve by Problem VI., as in the previous case (Problem XV.), we proceed as follows to obtain the particulars for the expansion valve. In the straight line *A B* (Fig. 25*a*) take any point *C*, and draw *C D* to represent the position of the crank, at which the port in the partition is to be open the given amount; and *C E* its position when the expansion valve is required to close the port and cut off the steam; and *C F* its position, at which it is found by Problem VI. that the main valve closes the port in the cylinder. Produce *F C* to *G;* and upon *C G* set off *C H* to represent the amount that we require the expansion valve still to be overlapping the port in the partition, at the moment the main valve closes the port in the cylinder. From the point *H* set off *H I* to represent the amount of lead which the expansion valve is to have, and this should of course be more than that of the main valve. Produce *D C* to *J*, and upon *C J* set off *C K* to represent the amount which the port is to be open for the given position *C D* of the crank. From the point *K* draw *K L* at right angles to *C J*, and through the point *C* draw *MN* at right angles to *CE;* and through the point *H* draw *NO* at right

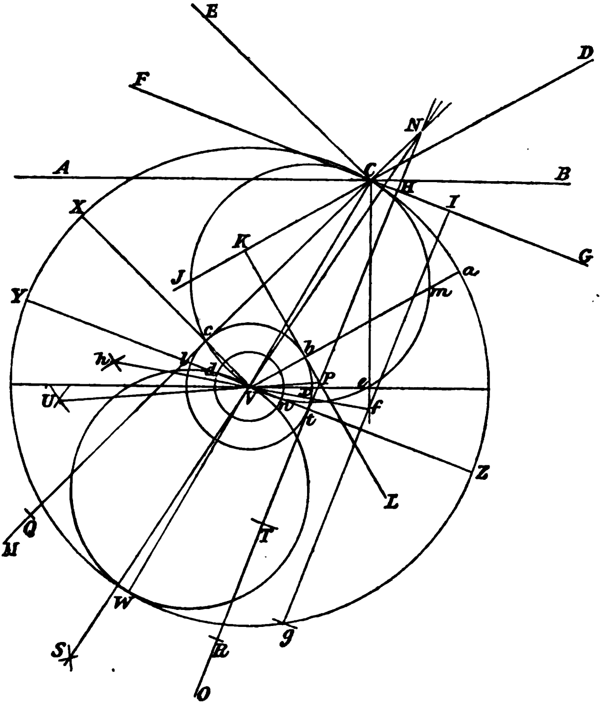


Fig 25a

angles to *CG*, intersecting the line *KL* in the point *P*, and the line *MN* in the point *N*. Upon these lines *NM* and *NO*, respectively, set off *NQ* equal to *NR*, and from the points *Q* and *R* as centres, with any convenient radius, describe arcs intersecting at any point *S*. Join *SN*. From the point *P*, where the lines *KL* and *NO* intersect, set off, upon the line *PO*, *PT* equal to *PK*. From the points *K* and *T* as centres, with any convenient radius, describe arcs intersecting at any point *U*. Join *UP*, cutting the line *NS* in the point *V*. Then, taking the point *C* to represent the centre of the expansion sheave, the point *V* will represent the centre of the crank shaft. Join *CV* and produce this line to *W*, making *VW* equal to *VC*. Then *VC* will represent the throw of the expansion sheave, and be the diameter of the primary and *VW* that of the secondary expansion circle; upon these diameters describe the respective circles, and from the point *V* as centre describe the lap circle touching the lines *NM*, *KL*, and *NO*. Draw *VX* and *VY* parallel to *CE* and *CF* respectively, and *Va* parallel to *CD*. It will now be quite evident that at the position *Va* of the crank, corresponding to the given position *CD*, *Va* being drawn parallel to *CD*, the port in the partition is open an amount, *bm*, equal to *KC* the given amount; and that the expansion valve closes the port in the partition and cuts off the steam at the position *VX* of the crank, corresponding to the given position *CE*; and further that the expansion valve is still overlapping the port in the partition by an amount *dl* equal to *nt* equal to the given amount CH, at the position VY of the crank, corresponding to the given position CF, at which the main valve is found to have just closed the port in the cylinder. We have now to see that the lead is of not *less* than the required amount HI, for as we are dealing with the expansion valve there is no objection to its being *greater;* and indeed, in order that neither the required opening of the port at the given position of the crank, nor the lead itself, shall be *less* than of the given amount, it will be frequently necessary to have the one or the other in excess of that amount. In the diagram before us (Fig. 25*a*) we find that the lead xe is exactly equal to the given lead HI, but assuming that it is of *less* than the given amount, we proceed as follows. Join Ce and produce it. From the point I draw Ig at right angles to CG, cutting the line Ce, produced, in the point f; from this point set off fg equal to fC, and from the points C and g respectively, as centres, with any convenient radius, describe arcs intersecting at any point h. Join fh, cutting the line NS in a point, which in the present case happens to be V, but on the assumption that the lead xe is of *less* than the given amount HI, would be more remote from the point C than is the point V. Taking then this new point of intersection for the centre of our crank shaft, we get a lead equal to the given lead, whatever it may be, but we get at the same time a greater travel for our expansion valve, a greater lap for the valve itself, and, at the given position *Va* of the crank, an opening of the port greater than *b m*, the given amount of opening, which is not however of any disadvantage. We now combine the diagram for the main valve with that for the expansion valve; when we can, as before, at once obtain all the particulars referring to the distribution of the steam.

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